EVALUATION OF WINTER FEEDING SYSTEMS FOR CROP YIELD AND AGRONOMY, BEEF COW PERFORMANCE, METABOLISM AND ECONOMICS

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ABSTRACT

Two experiments were conducted during the winters of 2012-13 (yr 1) and 2013-14 (yr 2), to evaluate 3 winter feeding systems: (i) field grazing standing whole plant corn (SC) cv. ‘DKC 26-25’ (yr 1, CP = 9.5%, TDN = 66.1%; yr 2, CP = 9%, TDN = 69.8%), (ii) field grazing swathed barley hay (SB) cv. ‘Ranger’ (yr 1, CP = 13.2%, TDN = 56.8%; yr 2, CP = 10%, TDN = 61.9% and (iii) barley hay bales fed in drylot pens (DL) cv. ‘Ranger’ (yr 1, CP = 13.1%, TDN = 53.2%; yr 2, CP = 8.2%, TDN = 55.2%). Forages were allocated on a 3-4 d interval in SC and SB systems. The specific objectives were to compare crop yield and agronomy, beef cow performance, reproductive efficiency and system costs in experiment 1 (EXP 1); and ruminal pH, SCFA and ammonia concentration in experiment 2 (EXP 2). In EXP 1, 60 dry, pregnant Black Angus cows (yr 1, 644 kg ± 72 kg; yr 2, 672 kg ± 66 kg) at mid-gestation, stratified by body weight (BW) were allocated to 1 of 3 replicated (n=2) winter grazing treatments for 77 d in yr 1 and 78 d in yr 2. Increases in rib fat were greater (P = 0.02) for SC cows compared to SB cows (1.6 vs 0.3 mm, respectively). Estimated DMI was lower (P < 0.01) for SC cows (9.1 kg/d) compared to SB and BH cows (14.3 and 13.0 kg/d, respectively) which did not differ (P > 0.05) from each other. Calves born to cows grazing SC were heavier (P < 0.01) at birth compared to calves from SB and BH cows (43, 40 and 40 kg, respectively). Changes in cow BW and average daily gain (ADG) were lower (P < 0.01) and negative in year 2 (BW change, 23.8 and -4.9 kg; ADG, 0.3 and -0.1 kg for yr 1 and 2, respectively). The number of calves born in first 21 d was 44% higher (P < 0.01) in yr 1 compared to yr 2. Economic analysis revealed that total costs were greatest for BH ($2.75/cow/d) compared to SC and SB ($2.06 and $2.00 cow/d, respectively) systems. In EXP 2, 9 cannulated beef heifers were cycled through the 3 winter systems concurrently within EXP 1, in a replicated 3 × 3 Latin square design, for 63 d to evaluate effect

of forage type and day of allocation on rumen fermentation. Results from EXP 2 indicated an increase (P < 0.01) in minimum pH of cannulated heifers from d 1 to d 3 of forage allocation in SC and SB systems. Lower (P < 0.01) minimum and mean pH and increased duration and area (P < 0.01) under pH 5.8 were observed in yr 2 in SC and yr 1 in SB. In yr 2, total SCFA, acetate and propionate concentration increased (P < 0.01) in SB heifers, but butyrate concentration increased (P < 0.05) in SC heifers compared to yr 1. Ruminal fermentation was unaffected (P > 0.05) by day of forage allocation and yr of study in BH system. Results from EXP 1 and EXP 2 suggest that both SC and SB systems are cost effective alternatives to BH system, and do not negatively affect cow reproductive performance following winter grazing. However, yearly differences in weather and seeding date of forages can have a profound effect on nutrient composition of forages, and can cause variations in cow performance and rumen metabolism during the period of extensive winter grazing.

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LIST OF ABBREVIATIONS

AA	Amino-acids
ADF	Acid detergent fibre
AIA	Acid insoluble ash
BCP	Bacterial crude protein
BCS	Body condition score
BH	Drylot treatment fed barley hay bales
BUN	Blood urea nitrogen
BW	Body weight
Ca	Calcium
CH_4	Methane
CHU	Corn heat units
CP	Crude protein
Cr_2O_3	Chromium sesquioxide
d	Day
DL	Control drylot treatment
DM	Dry matter
DMI	Dry matter intake
DOB	Date of birth
GDD	Growing degree day
GI	Gastro-intestinal tract
h	Hour
ha	Hectare

iNDF	Indigestible neutral detergent fibre
IVDMD	In-vitro dry matter digestibility
LCT	Lower critical temperature
LRC	Lethbridge Research Centre
mL	Milliliters
mo	month
mV	Millivolts
N	Nitrogen
NDF	Neutral detergent fibre
NE_l	Net energy of lactation
NE_m	Net energy of maintenance
NE_p	Net energy of pregnancy and reproduction
NFC	Non-fibre carbohydrates
NH_3	Ammonia - N
NIRS	Near-infrared spectroscopy
NPN	Non protein nitrogen
P	Phosphorus
PEG	Polyethylene glycol
RDP	Rumen degradable protein
SARA	Subacute ruminal acidosis
SAS	Statistical analysis systems
SB	Field grazing treatment fed swathed barley
SC	Field grazing treatment fed whole plant standing corn

SCFA	Short chain fatty acids
TDN	Total digestible nutrients
TiO_3	Titanium trioxide
TNZ	Thermal neutral zone
TPN	True protein nitrogen
UDP	Undegradable protein
UIP	Undegradable intake protein
UUN	Urinary urea nitrogen
WCDDGS	Wheat corn blend of distillers grains
Yb_2O_3	Ytterbium oxide
yr	Year
%	Percentage

1 INTRODUCTION

The profitability of beef cow-calf operations depends on cost-effective and improved technologies that may reduce feed costs (Munson et al., 1999; Landblom et al., 2007). This is because feed costs (Miller et al., 2001; Larson, 2013), in particular winter feeding costs (Kaliel and Kotowich, 2010) constitute a major portion of the total annual costs in beef cattle production. Winter feeding costs alone account for more than two-thirds of the total annual feeding and management expenses in beef cow-calf production in western Canada (Kaliel and Kotowich, 2010). Traditionally, beef cattle have been confined to a drylot or intensive feeding system during colder winter months, and fed on stored or preserved forages (McCartney et al., 2004). The increased costs associated with drylot pen feeding, have subsequently resulted in the evaluation of alternative extensive grazing systems (McCartney et al., 2004; Van De Kerckhove et al., 2011; Krause et al., 2013).

Beef producers have adopted extensive grazing strategies to reduce fuel, equipment and labour costs associated with harvesting feed, transportation costs and manure removal field application in fall (Kelln et al., 2011). Increased efficiency in soil nutrient retention and increased forage quantity and quality in the subsequent year, was observed on extensive winter grazing sites from nutrient deposition of grazing animals, compared to a site where manure from intensive drylot pens was transported using equipment and spread on the field (Jungnitsch et al., 2011). A study by Kelln et al. (2011) evaluating bale grazing, swath grazing and straw-chaff grazing reported no negative effect on cow reproductive performance, with similar or improved cow performance to cows fed barley hay bales in drylot pens (Kelln et al., 2011).

Forages which retain nutrient quality during late fall (Jensen et al., 2001), and are high yielding providing maximum number of grazing days (Legesse et al., 2013) are the most suitable for winter grazing. These forages should be able to meet all the nutrient requirements of beef cows during the second trimester of pregnancy as a 680 kg pregnant beef cow in second trimester of pregnancy requires 50% total digestible nutrients (TDN) and 7.8% crude protein (CP) in the diet (NRC, 2000).

The planting dates of annual forages can be adjusted (McCartney et al., 2008; 2009) to produce more biomass later in the growing season when compared to perennial forages (Kilcher and Lawrence, 1979). However, input costs for growing annual forages are high, and include machinery, fuel, fertiliser, seed and environmental costs from tillage operations (McCartney et al., 2008; 2009). Cool season annual forages such as barley and oat were found to be economic and effective sources for winter grazing mid-gestation beef cows in western Canada (Kelln et al., 2011; Krause et al., 2013; Bailey et al., 2014). Recently, the introduction of low heat unit hybrid varieties of corn has led to grazing whole plant standing corn in extensive winter programs (Lardner, 2002;2004; Lardner et al., 2012). However, there is limited research data available from long term studies comparing cow performance and system economics when winter grazing cool and warm season annuals compared to conventional drylot system.

The objectives of this review are (1) to provide an overview on winter management of beef cows in western Canada; thus to provide a critical comparison between traditional drylot systems and extensive grazing systems and briefly discuss the effect on cow performance, soil nutrient composition and system costs ; (2) to review various forages used in extensive grazing systems; (3) to discuss various techniques used to evaluate crop agronomy; and (4) to review the apparent digestibility of forages and rumen fermentation characteristics.

2 LITERATURE REVIEW

2.1 Beef cow winter management in western Canada

Beef cattle operations need effective use of all available feed resources to adjust for environmental conditions without compromising cow performance. Energy requirements of beef cows will increase with decreasing ambient winter temperatures (Baron et al., 2006). Therefore, feeding management is very important to maintain the body condition of the cow. Any increase in ambient temperature above or below the thermal neutral zone (TNZ), which is in the range of 15 to 25 ˚C can influence animal behaviour, function and productivity (NRC, 1981). The maintenance energy requirement of a dry pregnant cow during the second trimester of pregnancy, managed under wet snow and low wind condition increases by 2 Mcal/d (NRC, 1981). However, cows can gradually adapt to environmental stressors, making it possible to preserve body reserves amidst the extreme cold climate (Keren and Olson, 2006; Kelln et al., 2011; Petersen et al., 2014).

Physiologic and metabolic adaptation by the dam can compensate the impact of external stressors on depletion of tissue reserves, without compromising fetal nutrient requirement, during the initial stages of gestation (Camacho et al., 2014; Coleman et al., 2014). Freetly et al. (2005) reported that any nutritional compromise during mid-pregnancy will be compensated in the late stage of pregnancy, without affecting cow fertility or calf birth weight. This suggests greater flexibility in nutrient management, thus making the second trimester of pregnancy pivotal from an economic perspective (Cushman et al., 2014). Hence, considerable economic savings can be achieved without a loss in performance, by providing alternative and good quality feed resources during mid-gestation (Krause et al., 2013).

Matching a period of low feed availability (Camacho et al., 2014) when minimum cow metabolic requirements are needed (Freetly et al., 2005), western Canadian cow calf operations usually manage breeding programs in summer and the pregnant cows are fed in drylot pens during winter, followed by calving in the spring (Durunna et al., 2014). The winter feeding period usually lasts from 150 (Larson, 2013) to 200 d (McCartney et al., 2004) from late October to early May in western Canada.

The vast majority of beef producers depend on feeding conserved forages to cows in confinement pens (drylot pens) during winter (Baron et al., 2004). These confined system result in increased feed costs, from mechanically harvesting feed, baling, transportation and hauling manure to the field in spring (Jungnitsch et al., 2011).

2.2 Beef cow nutrient requirements

A well balanced nutrition program is important for a beef cow to perform most efficiently and nutrient requirements will vary with individual animal, location and weather conditions. Understanding these requirements and managing feed accordingly is the greatest challenge to a beef producer.

2.2.1 Energy

Energy is the nutrient of primary importance in beef cattle production in western Canada. A beef cow requires 1) energy for maintenance (NE_m) functions (Ensminger et al., 1990), such as body temperature regulation, essential metabolic processes and physical activity, 2) energy for lactation (NE_l), 3) energy for tissue growth and replacement of worn out tissue, tissue repair, synthesis of biomolecules, enzymes and hormone function (Riaz et al.) and 4) energy for pregnancy and reproduction (NE_p) (NRC, 2000).

The NE_m is defined as the amount of feed energy intake that will result in no net loss or gain of energy from the animal's body (NRC, 2000). The cow maintenance energy demands are proportional to the metabolic weight and body condition (NRC, 2000). Also, about 70 to 75 % of the total annual energy requirements of a beef cow are for maintenance regardless of the cow type (Ferrell and Jenkins, 1985; Montano-Bermudez et al., 1990). This is influenced by several factors such as body weight (BW), breed, genotype, sex, age, physiological state, season, temperature and previous nutrition (NRC, 2000). Thus maintenance energy (ME) requirements show considerable variation between animals and differing climatic conditions (Koberstein et al., 2001), and are greater than the requirements for growth, gestation and lactation (Ferrell and Jenkins, 1985).

Cold weather increases NE_m demand to a considerable extent (NRC, 2000) . When the environmental temperature starts to decline below the thermoneutral zone (TNZ), the animal needs to increase the metabolism to maintain body heat, which consequently increases NE_m requirements (NRC, 2000). The lower end of TNZ is called lower critical temperature (LCT), which is 0°C for beef cattle with BCS 2.5 to 3.0 and a dry winter coat. The following equation shows the variation in maintenance energy requirements with a decrease in environmental temperature below lower critical temperature (LCT) and body fat thickness.

Equation 2.1 $ME_c = SA\ (LCT-EAT)/IN$ (NRC, 2000)

Where, ME_c is the increase in maintenance energy requirement (Mcal/d), SA is surface area (m^2) (Lorenzen et al., 1993), LCT is lower critical temperature (°C), EAT is effective ambient temperature (°C) adjusted for thermal radiation, and IN is total insulation (°C/Mcal/m^2/d).

2.2.2 Protein

A beef cow uses protein to replace tissue breakdown from the body, hair, horn and hoof growth (Ensminger et al., 1990), metabolic processes and growth and reproduction of ruminal flora and fauna (NRC, 2000). A dry cow in early to mid-gestation requires 7 to 8% of crude protein (CP) in the diet for maintenance which increases to 11 to 13% CP in young growing or lactating cows (NRC, 2000).

Ruminants obtain protein from the diet either as rumen degradable protein (RDP) and rumen undegradable protein (UDP). Rumen degradable protein is furthur divided into non protein nitrogen (NPN) and true protein nitrogen (TPN). Ruminal microbes further degrade TPN, releasing peptides and amino acids (AA) which can be used for bacterial crude protein (BCP) synthesis (NRC, 2000). The TPN is deaminated to ammonia (NH_3) to be absorbed and converted to urea (Storm and Ørskov, 1983; Bach et al., 2005). Rumen microbes also have the unique ability to utilise non protein nitrogenous (NPN) sources as a cheap source for protein biosynthesis (Polan, 1988). Overall, it is estimated that ruminal microbial protein constitutes 50 to 80% of the total absorbed amino acids from the small intestine (Storm and Ørskov, 1983; Clark et al., 1992).

Several factors like feed degradability, available energy content and retention in the rumen can influence the ability of microbes to convert dietary protein to microbial protein which is useful to the animal (Storm and Ørskov, 1983). Therefore effective utilization of dietary nitrogen (N) is essential for optimal synthesis of BCP without being excreted from the body (Clark et al., 1992; Reynal et al., 2005).

2.2.4 Vitamins and minerals

Beef cattle require 17 essential minerals according to NRC (2000), and 7 are needed in greater quantities and are called macrominerals; calcium (Ca), phosphorus (P), magnesium (Mg), potassium (K), sodium (Na), chlorine (Cl), and sulphur (S). The remaining 10 are called microminerals and are required in lower quantities (NRC, 2000). These include chromium (Cr), cobalt (Co), copper (Cu), iodine (I), iron (Fe), manganese (Mn), molybdenum (Mo), nickel (Ni), selenium (Se) and zinc (Zn). Forage mineral content can be affected due to changes in soil, season and stage of maturity (Kappel et al., 1985). Animal mineral requirements can also vary with the stage and level of production (Greene, 2000). Because of this reason, mineral supplementation often becomes necessary for optimal reproduction, immune function, lactation and growth (Greene, 2000). At the same time, over supplementation of certain minerals can result in toxicity and can also pose environmental issues from leaching of excess minerals from animal wastes (NRC, 2000).

Vitamins are classified into fat soluble (A, D, E and K) and water soluble (B_{12}, thiamin, niacin, choline and vitamin C) types. Ruminants essentially obtain vitamin A and E from the diet (Wiess and Ferreira, 2006). Supplementation of vitamin A to pregnant cows before (16,000 IU/d) and after (40,000 IU/d) calving was found to increase conception rates by 10 percent and reduce calf morbidity by 50% (Hess, 2010). Beef cattle can synthesize vitamin D on exposure to sunlight or sun-cured forages (NRC, 2000). Bovine kidney and liver cells can synthesize vitamin C (Wiess and Ferreira, 2006). Ruminants do not depend on feed sources for vitamin K and B-vitamins as these are synthesized in sufficient quantities by the ruminal and intestinal bacteria (Wiess and Ferreira, 2006).

2.2.3 Water

Water constitutes 50 to 80 % of the animal's body weight (BW) (NRC, 2000), which makes it an important nutrient. An animal meets its water demand from 1) free drinking water, 2) water present in the feed and 3) metabolic water produced by the oxidation of organic nutrients (NRC, 1981). Water has an important role in body temperature regulation and vital organ function such as digestion, absorption and removal of wastes from the body. Animal performance can be negatively affected by restricted water intake. Severe water restriction has resulted in a lower dry matter intake (DMI) (Utley et al., 1970; Sejrsen et al., 2006).

Major factors affecting water requirements of beef cattle are DMI, environment, stage and type of production (Lardner et al., 2005). Consumption of high energy feeds or feeds high in metabolic water content decreases water requirement of the animal (Rasby and Walz, 2011). Environmental factors like daily temperature, humidity, wind velocity and time of day can also influence water intake (Ali et al., 1994). Water intake is found to be increased at higher temperatures (NRC, 1981) and is close to double the requirements for lactating cows compared to dry, pregnant cows (Lardner, 2003b; Lardner et al., 2005).

Grazing cattle on rangeland will utilize dugouts, riparian areas, ground water (wells) and snow as water sources. Water supplies get more difficult to access and expensive to operate during winter in western Canada (Thomas, 1999). Snow grazing can potentially lower production costs, when there is a reduced availability of drinking water (Young and Degen, 1991). Dry, pregnant beef cows were found to utilize snow as water source without any negative effect on BW, body condition or reproductive performance (Young and Degen, 1991).

2.3 Winter grazing systems

Winter grazing systems can be broadly classified into either intensive system (drylot) or extensive system. Several studies have been conducted comparing the efficiency of the intensive systems of managing beef cows in drylot pens during winter to extensive programs utilizing annual and perennial forages (Fredeen et al., 1988; Willms et al., 1993; Volesky et al., 2002; McCartney et al., 2004; Kelln et al., 2011).

2.3.1 Beef cow performance

Cattle grazing fescue pasture (*Festuca spp.*) in the fall and kept in drylot pens in winter outperformed cattle managed on native fescue prairie during both fall and winter (Willms et al., 1993). Kelln et al. (2011) reported that cows fed barley hay bales in drylot pens had greater or similar performance compared to cows managed on bale grazing, swath grazing or straw-chaff grazing. Improved cow performance was also reported by Krause et al. (2013) for cows fed grass-legume hay in drylot pens compared to cows managed with supplemented oat and pea crop residues during winter. Swath grazing cows in Alberta were found to consume more energy (18 to 21%) in the field than cows in a drylot system, and the swath grazing cows had lower BW gains, however BCS and reproduction efficiency were not affected by either system (McCartney et al., 2004).

In contrast, results from several studies showed improved animal performance in extensive grazing systems compared to conventional drylot systems (Adams et al., 1994; Volesky et al., 2002). Jungnitsch (2008) observed slight gain in BW and condition in beef cows managed on pasture feeding systems (bale processing and bale grazing) compared to drylot system. Calves grazing windrowed forage on sub-irrigated meadows in Nebraska were heavier than those fed hay in drylot, with this being attributed to the consumption of the high quality regrowth of meadows that occurred after haying (Volesky et al., 2002). Environmental factors such as extreme cold conditions, snow depth and wind can have a negative impact on animal productivity in extensive grazing programs, which can be minimized to a certain extent by adopting proper animal management practices such as ensuring availability of feed, water, bedding and artificial shelters such as portable wind breaks (Kelln et al., 2011).

2.3.2 Soil nutrient recycling

Animal excreta including nitrogenous wastes are excellent sources of nutrients that can be readily available in the soil for subsequent forage production (Jungnitsch et al., 2011). It also contribute to preventing soil erosion and surface water runoff by increasing the water holding capacity of the soil (Hudson, 1994; Kelln et al., 2012). According to Satter et al. (2002) recycling of forage nutrients, especially the N and P excreted in animal manure, back into the pasture to fertilize the soil and further utilization for crop production, remains a fundamental challenge to the livestock and feed industry. Most of the proteins in ruminant diet are highly digestible (Satter et al., 2002). However, the average N utilization in cattle ranges only between 15 to 40% of the total N consumed in the feed (Calsamiglia et al., 2010). A substantial proportion of absorbed N gets wasted as urea in the animal excreta without being utilized by the animal (Bierman et al., 1999; Calsamiglia et al., 2010).

The traditional management of livestock manure involves removal from drylot pens each spring and utilized later for fertilizing fields in either raw or composted form (Rotz, 2004). Such a system can result in very high losses of N through volatilization (57 to 67%) and surface runoff (5 to 19%) (Bierman et al., 1999). In addition, a significant loss of soil P can also result from runoff or by accumulation in the deeper soil layers in a conventional drylot system (Todd et al., 2004).

Extensive grazing of cattle can allow for a more uniform distribution of manure having a beneficial effect on soil nutrients and crop biomass production (Kelln et al., 2012). Jungnitsch et al. (2011) observed a greater efficiency of recycling of winter fed nutrients in the soil and pasture in subsequent years of winter feeding, on sites receiving extensive winter grazing systems (bale grazing and bale processing) compared with feeding cattle in a conventional drylot system and spreading the manure or compost with equipment. Pasture forage DM yield measured on the previously overwintered pastures was found to be greater than those sites where manure was mechanically spread from drylot pens (Powell et al., 1998; Jungnitsch et al., 2011). Meanwhile around 30 to 40% and 20 to 30% of original feed N and P, respectively, was recovered in pasture forage, in the pasture feeding systems compared to only 1 and 3%, N and P, respectively, recovered in the system where manure was taken from drylot pens and spread onto the field (Jungnitsch et al., 2011).

2.3.3 Feeding system economics

Winter feeding costs alone can account for 65 to 70% of the total annual feeding and management expenses in beef cow-calf production in western Canada (Kaliel and Kotowich, 2010). This is in agreement with McCartney et al. (2004) and Nayigihugu et al. (2007) who calculated that winter feeding costs were 60 to 65% and 60%, respectively of the total beef production costs.

Extensive winter grazing systems have been found to have considerable economic advantage over conventional drylot systems, in reducing winter feeding expenses (Bowman and Sowell, 2003; Jungnitsch et al., 2011; Kelln et al., 2011; Krause et al., 2013). Winter feeding costs accounted to \$0.16, \$0.31, \$0.83 and \$0.86 per cow/d and total production costs averaged \$1.27, \$0.76, \$0.98 and \$1.07 per cow per d for straw–chaff grazing, swath grazing, bale grazing and drylot feeding, respectively (Kelln et al., 2011). While supplementation and associated costs increased production costs in straw-chaff grazing (Kelln et al., 2011), increased costs in the drylot feeding system were often due to the higher costs associated with machinery and labour (Volesky et al., 2002; McCartney et al., 2004; Kelln et al., 2011). According to McCartney et al. 2004, labour costs of a swath grazing system were 38% less compared to feeding in drylot pens. However, windrow grazing was found to be less economical compared to bale feeding because of the higher costs involved in watering livestock and feed wastage in the swath grazing system (Nayigihugu et al., 2007).

2.4 Extensive grazing systems

There has been considerable research conducted on the various strategies adopted for extensive winter grazing in western Canada (Kelln et al., 2011; Kumar et al., 2012; Krause et al., 2013). Maintaining forage quality and availability to match the grazing animal requirements in the extreme cold weather, is the greatest challenge in any overwintering system. Wind protection, and use of natural shelter-belts or portable wind breaks, provision for clean drinking water and allocation of feed using electric fences to control animal access should be considered in any extensive winter feeding strategy.

2.4.1 Swath grazing

Swath grazing is the method of grazing late spring seeded annual crops harvested at soft to mid dough stage, and left in windrows in field paddocks for beef cattle grazing (Legesse et al., 2012). ‘Swathing consolidates forage so that it can be more easily apprehended than standing biomass by cows grazing through snow’ according to Baron et al. (2006). This is relevant in western Canadian climatic conditions, since snow can act as a hindrance to the forage accessibility by grazing animals (Lawrence and Heinrichs, 1974; Baron et al., 2006; Kelln et al., 2011).

Adams et al. (1994) observed that grazing time and DMI of grazing animals can be negatively affected on a native range by extreme cold weather. Increasing forage access by swathing and windrowing can improve DM and energy intake, thereby maintaining animal weight and body condition (Baron et al., 2006).

Cool and warm season annuals have been evaluated for their potential to meet the demands of calves, cows and stocker cattle for fall and winter grazing (Entz et al., 2002). Apart from the high annual initial input costs such as machinery, fuel, fertiliser, seed and tillage operations, annual forages are found to be well suited to swath grazing because of the flexibility in planting dates (McCartney et al., 2008) and their ability to bring forth good quality forage, resulting in better seasonal biomass distribution (Entz et al., 2002).

2.4.2 Bale grazing

Hay bales can be fed to cows either 1) by allowing direct grazing of round bales out in the field (bale grazing), 2) processing the round bales, to shred the hay on the ground for grazing (bale processing) or 3) by feeding baled hay in a tapered-cone round bale feeder in an intensive system (drylot system) as described by Landblom et al. (2007). Bale grazing itself can be 1) extensive bale grazing or 2) intensive bale grazing (SMA, 2008). In the intensive system, bales are placed on a grid about 12 m apart, with an approximate density of 60 bales/hectare. In extensive systems, bales are left on the spot in the field, where they are ejected from the baler, which equates to around 5 bales/hectare.

A study comparing bale feeding systems found that use of tapered-cone round bale feeders reduced feed wastage and reduced wintering costs compared to bale processing, but still maintained cow body condition (Landblom et al., 2007). Extensive grazing strategies like bale processing and bale grazing exhibited some advantages like better nutrient recycling efficiency, increased forage yield and reduced system costs (Jungnitsch et al., 2011; Kelln et al., 2011) when compared to feeding in a round bale feeder in drylot pens. Bale processing, further helped in spreading feed and manure more uniformly, resulting in better forage yield and grass regrowth potential (Jungnitsch et al., 2011). However, out of all the winter grazing systems compared, bale grazing systems showed the least uniformity in manure nutrient deposition in the field (Lardner et al., 2007; Kelln, 2010). There can be potential dead spots in and around the area where bales are placed, that can impede forage growth in the subsequent year (SMA, 2008).

2.4.3 Stockpile grazing

Stockpile grazing is a system of preserving forages to grow and accumulate biomass during late summer and fall and allow cattle to graze these forages later in the fall and winter (Riesterer et al., 2000). The choice of forage species used for grazing, accumulation period and management of soil nutrients play an important role in the success of stockpile grazing (Matches and Burns, 1995). Prolonged accumulation period can increase yield, but detiorate quality (Baron et al., 2005). Perennial forages, and some spring or winter cereals can be used for stockpiling either as standing crop or as windrowed feed (Dick et al., 2008).

Baron et al. (2004) provides an overview of the forages used for stockpiling on the Canadian western prairie parkland. Tall fescue (*Festuca aruninacea* Schreb), Altai wild ryegrass (*Laymus angustus* Trin) and some native grasses provide good regrowth potential suited for fall grazing and can prevent weathering to some extent, making it ideal for stockpiling (Baron et al., 2004). Legumes are less preferred for stockpiling because of the decline in nutritive value, resulting from leaf loss during frost or by maturity (Matches and Burns, 1995).

Stockpiled forage may be of moderate to poor quality (Dharmasiri Gamage, 2014). Hence, proper management practices become crucial while adopting this system (Riesterer et al., 2000). Over maturity, sorting by animals, leaf losses by weathering, reduced accessibility due to snow are some of the concerns associated with this grazing strategy, and supplementation may be necessary under certain circumstances when the forage fails to meet the animal's nutrient demands (Dharmasiri Gamage, 2014).

2.4.4 Crop residue grazing

Cereal crop residues like straw and chaff, are easily available and have low economic value, making them substantial sources for feeding beef cattle (McCartney et al., 2006). However, the nutritive content of residues is low compared to other feeds, which makes supplementation often necessary (McCartney et al., 2006).

In a study conducted by Van De Kerckhove et al. (2011), cows in mid-gestation grazed barley crop residue, supplemented with either 1) 100% wheat-corn blend dry distillers grains plus solubles (WCDDGS), 2) 50% WCDDGS and 50% rolled barley or 3)100% rolled barley. The authors observed a higher BW gain ($P < 0.01$), for cows in the WCDDGS and 50:50 treatments (11.3 and 6.8 kg, respectively), compared to the 100% rolled barley treatment (-6.5 kg), and thus concluded that cow performance can be influenced by the type of supplementation. In another study by Kelln et al. (2011), where a range pellet was supplemented to cows grazing barley straw-chaff residues, the system costs exceeded those of the drylot system ($ 1.27/d vs. $1.07/d), yet cow BW gain remained comparatively positive to drylot feeding (6.2 vs. 28.2

kg/cow), averaged over the 3 year study. However, cow reproductive performance was not negatively affected (Kelln et al., 2011). System costs were lower for grazing oat and pea residues in a study comparing field grazing crop residues to pen feeding grass-legume round bales in drylot (Krause et al., 2013). Yet final BW gain was found to be lower ($P = 0.01$) for cows grazing oat and pea residue compared to cows managed in drylot, 26.5 and 3.7 vs. 65.9 kg/cow, respectively.

These studies suggest that crop residue grazing can be alternative to drylot feeding in reducing system costs but their success greatly depends on the adoption of effective supplementation strategies to meet grazing animal nutrient requirements.

2.4.5 Whole plant corn grazing

Growing corn as a winter grazing crop for beef cattle has been more limited to the southern areas of eastern Canada, or southern areas of the prairies (McCartney et al., 2009). Successful growth of corn depends on the availability of crop heat units (CHU), and is considered more suitable to areas receiving a minimum of 2000-2100 CHU's (McCartney et al., 2009). Corn is a warm season annual, usually seeded late with variation in the date of maturity depending on the geographic location and the available CHU's (May et al., 2007). However, early seeding of late maturing hybrid varieties of corn has immense potential for use in extensive winter grazing systems (SMA, 2008).

McCaughey et al. (2008) observed that the carrying capacity and forage quality at the time of consumption were better, when corn forage was swathed than when it was left standing. However, grazing trials at Lanigan, Saskatchewan suggested that corn can serve as an excellent winter foraging crop, left either standing or swathed (Lardner, 2002). May et al. (2007), conducted small plot trials at Indian Head, Saskatchewan, and found that corn had variable yield, and in some cases yielded similar to oat or barley and was marginal in meeting CP requirements for pregnant beef cows. Standing corn can also serve as an effective windbreak for grazing cattle during winter and snow depth will not limit animal access to the crop as corn stands well above the ground (Baron et al., 2003). Despite these advantages, producers are unsure in using corn for overwintering beef cows due to high input costs arising from weed management, seed and fertiliser costs, and the high variability in dry matter yield (McCartney et al., 2009). There is limited multi-year research conducted on comparing the potential of corn for winter grazing in relation to other annual crops like oat, barley and fall rye (McCartney et al., 2009).

2.5 Forages used in extensive grazing system

To allow grazing through the snow easy and efficient, forages used for winter grazing should yield a minimum of 2000 kg/ha biomass (Dick et al., 2008). Additionally, forage nutrient quality should be optimum for meeting the grazing animal demands (NRC, 2000). Species selection is therefore very important in an extensive grazing system. Forages utilised for extensive grazing systems can be classified either annual or perennial forages. Annual forages can be either cool or warm season varieties.

2.5.1 Annual forages

2.5.1.1 Cool season annuals

Barley (*Hordeum vulgare* L.), oat (*Avena sativa*) and triticale (× *Triticosecale Wittmack*), a hybrid between wheat (*Triticum*) and rye (Secale cereal L.), are traditionally the most widely used small grain cereals for grazing in western Canada (SMA, 2008; Rosser et al., 2013). Winter cereals like fall rye, winter wheat and winter triticale has also been used to some extent (SMA, 2008).

Oat out-yielded other early maturing annual forages in forage yield according to Kibite et al. (2002). Lardner et al. (2011) reported that dry pregnant beef cows grazing either swathed oat (*Avena sativa*) or proso millet (*Panicum miliaceum*), maintained their body condition throughout winter.

At the same stage of development, and regardless of site and seeding rates, barley had higher *in-vitro* dry matter digestibility (IVDMD) and CP compared to oat (Kibite et al., 2002), however barley yield was 15% lower compared to oat and triticale in demonstration plots conducted at Lacombe, Alberta from 2004 to 2006 (McCartney et al., 2009). Kibite et al. (2002) also reported that oat crop had the greatest yield where growing seasons were longer and rainfall higher whereas barley had higher yields in areas with a drier and shorter season.

Triticale (× *Triticosecale Wittmack*) has similar grain quality and productivity of wheat and the vigor and hardiness of rye (Oelke et al., 2014). It is well suited for late fall grazing with dry pregnant beef cows and is similar to barley and oat in nutritive value, but forage yield can be comparatively low.

According to Walton (1975) wheat gave consistently lower yields compared to oat and barley. In simulated grazing trials, fall rye and winter wheat produced less DM, but more protein than oat (McCartney et al., 2008).

2.5.1.2 Warm season annuals

The potential of warm season annual crops for extending the grazing season in Canada, has been reviewed by McCartney et al. (2009). Corn (Gutierrez-Ornelas and Klopfenstein, 1991), sorghum (Beyaert and Roy, 2005), millets, brassica crops and turnips are other forages being evaluated for overwintering beef cattle.

Standing corn is becoming more popular as a winter grazing forage in western Canada, due to the introduction of low heat unit corn hybrids (Lardner, 2002). These hybrid varieties can produce high levels of biomass even at cooler grazing conditions. Corn is considered to have high nutritive value, but also demands higher input costs (McCartney et al., 2009).

Several grain and forage varieties of sorghum have been introduced to Canada recently, for use in winter grazing pastures (Beyaert and Roy, 2005). These crops have advantages over corn, being more drought resistant (Fribourg, 1973), and growing well at temperatures between 25 to 30˚C (McCartney et al., 2009). According to Klopfenstein (1994), grain varieties of sorghum are superior to corn stalks for winter grazing, due to higher proportion of standing leaves above the snow and a higher protein of leaves compared to corn leaves. However, present varieties of Sorghum-Sudan grass were found not suitable for swath grazing in Saskatchewan (May et al., 2007).

Millets includes a wide range of cultivated semi-arid tropical annual grasses such as proso millet (*Panicum miliaceum* L.), foxtail millet (*Setaria italic* L. Beauv.), pearl millet (*Pennisetum glaucum* L.R. Br.) and Japanese millet or barnyard millet (*Echinochloa frumentaceae L.*) (McCartney et al., 2009). Foxtail millet is taller, late maturing, more palatable and more suited to forage production compared to proso millet. According to McCaughey et al. (2008), foxtail millet is more suited to arid regions of western prairies, whereas Golden German foxtail millets were more suitable for high rainfall areas with heavier darker soil. They also suggested that in regions where temperature ranges from 32 to 35 °C, millets can be a good alternative for fall and winter swath grazing. Production costs for growing millet were comparable to other cereals used for swath grazing at Lanigan, Saskatchewan (Lardner, 2002;2004). May et al. (2007) suggested that a combination of German foxtail millet with oat and barley can provide a suitable biomass over time.

Fall and winter Brassica crops include kale (*Brassica oleracea* L.), forage rape (B. *napus ssp. biennis* L.) and swedes or rutabagas [*B. napus* L. *var.napobrassica* (L.) Rchb.]. Stubble (white) turnips (*B. rapa* L.) and their hybrids can be used for grazing (Aasen and Bjorge, 2009; McCartney et al., 2009). However, these plants have high moisture content and low CP content which makes supplementation often necessary (Guillard and Allinson, 1988; McCartney et al., 2009). This can eventually result in higher system costs (Lardner, 2003a). High labour costs and increased susceptibility to diseases caused by fungi and pests are other reasons that make them least popular for extensive grazing (McCartney et al., 2009).

2.5.2 Perennial forages

Tall fescue (*Festuca arundinacea*) is the most desirable grass to stockpile for late fall and winter grazing (Caldwell et al., 2009). Tall fescue has high concentrations of non-structural carbohydrates, low concentrations of fiber, high digestibility (Burns and Chamblee, 2000) and has the ability to produce more autumn growth than other cool-season forages (Poore et al., 2000). However, high endophyte concentrations (Tucker et al., 1989) and nutrient losses caused by weather (Bagley et al., 1983) have resulted in poor performance in cows grazing tall fescue.

Smooth bromegrass (*Bromus inermis Leyss*) responds very well to nitrogen fertilization. When established in association with alfalfa, it can utilize N fixing properties of alfalfa to bring forth better forage yield and quality (Legesse et al., 2012). Meadow bromegrass (*Bromus* *riparius Rehm*) has less winter-hardiness than smooth bromegrass or crested wheatgrass (*Agropyron cristatum*) (Vogel et al., 1993), but has better regrowth potential than smooth bromegrass (Knowles et al., 1993). Crested wheatgrass is particularly suited to early spring and late fall grazing in the central Great Plains (Vogel et al., 1993). When this species reaches maturity, it becomes unpalatable and quality declines rapidly, which may limit its use to spring and fall grazing (Smoliak et al., 1981).

Alfalfa (*Medicago sativa*, also called Lucerne) provides high forage yields and exceptional forage quality, that contribute to high rates of live-weight gain (Douglas, 1986). The nutritional value and yield of tame pastures have been enhanced by the inclusion of alfalfa in the Parkland region of western Canada (Popp et al., 2000). Pregnant dry cows grazing alfalfa-grass pasture required less fertilizer, and exhibited higher cow and calf BW gains ($P < 0.05$) for 3 consecutive production years in Manitoba (Legesse et al., 2012). Effective management and monitoring of mixed perennial pasture is required for its use in extensive grazing systems, due to reductions of DM yield and quality with time (Baron et al., 2004; Legesse et al., 2012).

2.5.3 Crop residues

Corn crop residue is one of the highest quality residue forage (Wright and Tjardes, 2004). Digestible DM in corn residue is equivalent to approximately 35% of the amount produced in corn grain (Gutierrez-Ornelas and Klopfenstein, 1991). However, corn residue is quite low in most minerals such as Ca and P and also vitamin A. As a result, a well-balanced vitamin and mineral mix should be provided free-choice, when the cows are managed on corn residues. In addition, without supplemental protein, the forage digestibility will decrease, and the forage will not be able to meet the nutritional requirements of the animal (Wright and Tjardes, 2004).

Barley straw-chaff is the residue obtained after the harvest of barley grains, which can be used for grazing dry pregnant beef cows. However, the need of supplementation increased system costs when compared to swath grazing, bale grazing and drylot system (Kelln et al., 2011). Supplementation with wheat-corn blend DDGS was found to improve performance of beef cows consuming barley straw-chaff piles (Van De Kerckhove et al., 2011).

Grazing either oat or pea crop residues in field paddocks was 34 and 26% lower, in cow cost per day compared to winter feeding hay to cows in drylot pens (Krause et al., 2013). Beef cows grazing oat residue piles and provided adequate energy supplementation in field paddocks, had positive BW change and similar rib and rump fat, as those cows fed grass-legume hay in drylot pens (Krause et al., 2013).

2.6 Factors affecting grazing animal performance

The performance of a grazing ruminant depends on its ability to consume and utilise energy from the available feed resources (Allen, 1996). Availability of forage biomass, chemical composition and digestibility are as crucial as the animal's physiologic characteristics in determining the intake potential of a grazing ruminant (Burns et al., 1994). Therefore, animal productivity in more abstract terms is the product of feed supply, forage nutrient and energy concentration, dry matter intake, forage digestibility and rumen metabolism, as reported by Mertens (1994). A detailed description of these parameters and the methods employed for their determination will be discussed further.

2.6.1 Forage availability and nutrient density

Forage quantity and quality estimations are good tools for devising management strategies to improve animal productivity (Sollenberger and Cherney, 1995). Animal productivity is greatest when forage supply exceeds animal demand, provided forage quality is not compromised (Heath et al., 1973).

2.6.1.1 Estimation of forage availability

Forage available for grazing, or biomass production per ha, can be calculated from an estimate weight of the forage above a reference standard height or stubble height as described by Sollenberger and Cherney (1995). Forage biomass can be measured either by 1) a destructive technique where a number of forage sample units are collected from different parts of the field at random for estimating the forage yield in a unit area (Sollenberger and Cherney, 1995; Mannetje and Jones, 2000) or 2) a non-destructive technique which can be done by i) direct visual estimation by an experienced operator, ii) measurement of the height and density of the sward using drop disk, capacitance meter or remote sensors or by iii) measurement of non-vegetative attributes related to DM yield (Mannetje and Jones, 2000). Non-destructive techniques are less accurate compared to destructive techniques, but demand less time and labour (Mannetje and Jones, 2000).

2.6.1.2 Estimation of forage quality

Chemical composition of forages will vary with certain factors such as plant type, climate, season, weather, soil type and fertility, soil moisture, leaf stem ratio, physiological and morphological characteristics or a combination of these factors (Kilcher, 1981; Adesogan et al., 2000). The samples for chemical analysis should represent all forage structures being evaluated and are processed by oven drying and subsequent grinding to ensure uniformity and homogeneity of the samples before analysis (Sollenberger and Cherney, 1995). The ground samples are then analysed for nutrients like protein, fibre, fat and minerals by wet chemistry or near infra-red reflectance spectroscopy (NIRS) (Dharmasiri Gamage, 2014). Wet chemistry procedures uses established standard operating procedures for determination of protein, fibre, fat and minerals in feed. Nitrogen content of feed can be estimated using Kjeldahl or the combustion method (LECO). Determination of crude fibre (ADF and NDF) is usually done based on the digestion technique developed by Van Soest et al. (1991). The ether extract procedure is the method employed for crude fat analysis in forage samples (AOAC, 2012). Minerals are estimated using atomic absorption spectrophotometry (AOAC, 2012).

2.6.2 Dry matter intake (DMI)

Selective grazing by ruminants is a major constraint in DMI estimations (Church, 1975). The intake potential of a grazing animal for a particular forage, can be evaluated only if the forage is provided *ad libitum*, and the animal is given an opportunity to graze within the bounds of quantity and quality a forage can offer (Burns et al., 1994).

2.6.2.1 Direct methods of estimation

Dry matter intake can be estimated directly by either continuous weight monitoring or weighing animals before and after each grazing period or measuring the difference in herbage mass before and after grazing (Burns et al., 1994).

The need to account for losses due to urine, feces and respiration and non-forage (supplemental minerals, water and soil) are the major limitations with the weight monitoring technique. At the same time, overestimation resulting from consumption by non-experimental or wild animals and underestimation from the growth of sward during grazing period, are potential limitations while estimating DMI through herbage mass difference (Burns et al., 1994).

2.6.2.2 Indirect methods of estimation

Indirect estimations of DMI involves estimation of fecal output and forage digestibility (Burns et al., 1994). In grazing trials, where forage intake is difficult to estimate and total fecal collection remains laborious and impractical, fecal markers can be used to determine digestibility and intake (Cochran and Galyean, 1994). Fecal markers are measurable entities in the feces which are either present naturally in the feed and called internal markers or those dosed externally in the feed or through an external cannula called external markers (Dove and Mayes, 2006). The authors suggested the use of internal markers for estimating digestibility and external markers to determine fecal output under range conditions (Dove and Mayes, 2006).

2.6.2.3 Calculation of DMI

Estimates of fecal output and digestibility values can be calculated from the ratio of the respective markers in the feed and feces (Burns et al., 1994; Dove and Mayes, 2006). The values thus obtained can be combined to obtain DMI estimates using the following equations modified from Dove and Mayes (2006):

Equation 2.2 Fecal DM output (g/d) = $(EM_{fd} / EM_{fc}) \times 100$

Equation 2.3 Diet DMD (%) = $100 – 100\ (IM_{fd} / IM_{fc})$

Equation 2.4 DMI (g d^{-1}) = Fecal DM output (g d^{-1}) / 1 - (Diet DMD / 100)

Where, DM = dry matter; DMD = dry matter digestibility; EM_{fd} = daily dose of external marker (g); EM_{fc} = concentration of external marker in the feces (DM %); IM_{fd} = concentration of internal marker in the feed (DM %); IM_{fc} = concentration of internal marker in the feces (DM %).

The double alkane technique was first developed by Mayes et al. (1986) to estimate intake in grazing sheep. The technique involves dosing the animal with an even chain alkane which acts as an external marker (Mayes et al., 1986). The odd chain alkane, which is inherently present in the forage is used as an internal marker (Mayes et al., 1986). Feed intake is then calculated from the dose rate, and feed and fecal concentrations of the odd and even chain alkane markers (Dove and Mayes, 1991). The alkane technique has been widely used by scientists, for studies requiring intake estimation (Bugalho et al., 2002; Smith et al., 2007; Keli et al., 2008).

Other commonly employed internal markers include silica, lignin, fecal N, chromogen, acid insoluble ash (AIA), cellulose and indigestible neutral detergent fibre (iNDF) (Burns et al., 1994; Huhtanen and Kukkonen, 1995). External markers such as chromium sesquioxide (Cr_2O_3), titanium dioxide (TiO_2), ytterbium oxide (Yb_2O_3) and polyethylene glycol (PEG) have been used to estimate fecal output in grazing range conditions (Delagarde et al., 2010; Davis et al., 2014; Hassoun et al., 2014).

2.6.3 Forage dry matter digestibility

Forage digestibility is a critical factor that can influence forage intake and the performance of a grazing ruminant (Decruyenaere et al., 2009; Jančík et al., 2011; Hughes et al., 2014). Digestibility estimations are often found to be costly, time consuming and labour intensive under field conditions (Decruyenaere et al., 2009; Kanani et al., 2014). Moreover, selective grazing by free grazing animals adds to the inaccuracies in the prediction of digestibility (Boval et al., 2004).

Apparent digestibility is the difference between the nutrients consumed and the nutrients excreted in feces (Minson, 1990; Cochran and Galyean, 1994). Apparent digestibility can be estimated in the laboratory using direct (*in-vivo*) or indirect (*in-vitro* or *in-situ*) techniques (Lassiter and Edwards, 1982). Apparent digestibility differs from true digestibility, as it does not account for methane loss, unabsorbed digested nutrients in the feces and the endogenous secretions (Minson, 1990).

2.6.3.1 *In-vivo* technique

The *in-vivo* technique involves direct calculation of digestibility through estimation of total feces excreted and total feed consumed and is found to be more accurate compared to indirect methods (Gosselink et al., 2004; Jančík et al., 2011). Digestibility is calculated by subtracting the total amount of feces excreted from the total amount of feed consumed and dividing the remainder by the amount consumed (Streeter, 1969).

Equation 2.5 Digestibility = FC (g) - FE (g) / FC (g)

Where, FC = Total amount of feed consumed; FE = Total amount of feces excreted.

2.6.3.2 *In-vitro* technique

The *in-vitro* technique was initially developed by Tilly and Terry (1963). Several modifications of this method including the pepsin cellulose technique and gas production technique have been found to be efficient in predicting organic matter (OM) digestibilities with accuracy, and also exhibited a strong correlation with *in-vivo* methods (Mabjeesh et al., 2000; Gosselink et al., 2004; Decruyenaere et al., 2009). In the Tilly and Terry technique, digestibility is estimated by incubating feed samples in a buffer solution and rumen fluid from a donor animal (Tilly and Terry, 1963). However, the accuracy of *in vitro* dry matter digestibility (IVDMD) values obtained can be impacted by the rumen fluid innoculum and can show variation from individual donor animal, species, diet and management conditions (Cochran and Galyean, 1994).

2.6.3.3 *In-situ* technique

In-situ or *in-sacco* disappearance is estimated by incubating, previously weighed feed samples sealed in silk or nylon bags inside the rumen (Minson, 1990). The results may be affected by fabric type, size, uniformity of pores and bag size. Another challenge with this technique is the limitations to mimic the mastication and rumination activity to determine the particle size of the feed sample used for incubation (Cochran and Galyean, 1994). Apart from these factors, the diet fed to the animal used for incubation, method of inserting bags to the rumen, location of bags within rumen, rinsing technique adopted, bacterial attachment to particles within the bag can also impact the digestibility results (Cochran and Galyean, 1994).

2.6.3.4 Collection of forage samples

Under range conditions, the accuracy of *in vivo* and *in vitro* techniques is highly dependent on the collection of field samples that are representative of the ingested feed (Decruyenaere et al., 2009). Analysis of feed samples collected from oesophageally fistulated animals can overcome this limitation (Holechek et al., 1982), but a failure in representing the feed consumed has been reported by Coates et al. (1987).

2.6.4 Rumen metabolic parameters

2.6.4.1 Ruminal pH and SCFA production

Carbohydrates are the major constituents of plant tissue and the primary sources of energy for the host animal and the rumen micro-organisms (Church, 1975). Carbohydrates exist as complexes of monosaccharides or disaccharides and their distribution varies with agronomic and environmental factors and the age and species of the plant (Church, 1975). These carbohydrates undergo anaerobic fermentation in the rumen by interaction with rumen bacteria, releasing short chain fatty acids (SCFA) and energy as ATP for microbial use (Sutton, 1968). The SCFA produced are then absorbed by the gut epithelium into the systemic circulation (Nagaraja and Titgemeyer, 2007). Acetate, propionate and butyrate are the 3 major volatile fatty acids produced in the rumen, but others such as isobutyrate, valerate, isovalerate, caproate and isocaproate are also produced in minor amounts (Sutton, 1968). Monosaccharides exhibit a wide variation in their rate of fermentation in the rumen (Sutton, 1968). Diets high in forage will result in the production of a higher proportion of acetate, while diets high in concentrates result in the production of propionate in higher proportions (Sutton et al., 2003).

A disruption of the balance in the production and absorption of SCFA is reflected in a change in rumen pH (Garett, 1999). A rapid rate of SCFA production that exceeds the ruminal capacity to buffer the acids and maintain equilibrium can result in a drop of ruminal pH (Beauchemin and Penner, 2009). Ruminal pH often exhibits a diurnal variation, which is influenced by the type of feed consumed by the animal, the capacity to buffer excess acids produced from fermentation in the rumen and also the rate of acid absorption and utilization (Nagaraja and Titgemeyer, 2007; Schwaiger et al., 2013). The SCFA accumulation and the subsequent drop in ruminal pH below the normal physiologic range (70 to 150 mM/l) can have a negative impact on the microbial activity, rumen function and animal productivity and health (Nagaraja and Titgemeyer, 2007).

2.6.4.2 Microbial protein synthesis and ammonia production

The inherent ability of ruminants to utilise highly fibrous roughages for meeting their nutrient demands is through the unique symbiotic association that exists with the microbial flora that inhabit the rumen (Church, 1975). Microbial protein is a high quality protein with a digestibility of approximately 80% (NRC, 2000) and alone constitutes about 34 to 89% of the total duodenal non-ammonia N flow (Clark et al., 1992). Bacterial crude protein (BCP) can meet 50 to 100% of the total protein requirements of a beef cow, depending on the undegradable intake protein (UIP) content in the diet (NRC, 2000). Therefore, an economic ruminant protein nutrition regimen demands increased efficiency in providing rumen degradable protein, for microbial utilisation and growth, thereby limiting the amount of dietary undegradable intake protein (NRC, 2000).

Ruminal bacteria will attach to the feed particles reaching the rumen, thus degrading protein into peptides and amino acids (Bach et al., 2005). Peptides and amino acids are further transported into the bacterial cell and peptides are further degraded to amino acids. The fate of amino acids inside the cell depends on the availability of energy (carbohydrates). If energy is available, these amino acids can be either directly incorporated or transaminated for synthesis of microbial protein (Bach et al., 2005). When energy is limiting, amino acids will be deaminated, with the release of ammonia and the carbon skeleton being fermented to SCFA (Bach et al., 2005). The ammonia (NH_3) released as a result of this is absorbed into the portal circulation and being neurotoxic, is finally converted to urea in the liver (Chapa et al., 1998). When released into the blood, the blood urea nitrogen (BUN) is partially recycled into the gastro intestinal (GI) tract and the remaining BUN is lost through urine as urinary urea nitrogen (UUN) (Bach et al., 2005). Hence, the availability of total microbial N for use by the animal, depends on the amount of fermentable carbohydrate in the diet as well as the efficiency of microbial protein synthesis (Calsamiglia et al., 2010).

The efficiency of microbial protein synthesis is also enhanced by a synchrony in protein and carbohydrate degradation (Bach et al., 2005). However for forages, the protein degradation is comparatively faster than carbohydrates; in contrast to grains like corn and sorghum which exhibit a faster starch and slower protein breakdown (NRC, 2000). Ruminants can compensate for this inefficiency, by means of urea recycling and by consuming more than 1 meal per day (Archibeque et al., 2001; Obitsu and Taniguchi, 2009). However, the amount of urea recycled into the GI tract is found to exhibit a variation with the species, physiological state, environmental condition and diet.

2.6.4.3 Estimation of ruminal SCFA concentration and ammonia-N

Gas chromatography is the technique employed for the quantification of individual short chain fatty acids (Khorasani et al., 2001). The sample to be analyzed is vapourised and transported to a column that contains a liquid stationary phase. The rate of exit of chemicals (retention time) through the GC column is recorded electronically by a detector on their exit from the column. The retention time of fatty acids depends on their physical and chemical properties and interaction with the stationary phase, which inturn helps in quantification of individual fatty acids. Phenol hypochlorite reaction is the most suitable technique for NH_3-N determination, which involves saparation of ammonia from the sample using phenol and hypochlorite reagents followed by colorimetric determination of ammonia (Broderick and Kang, 1980).

2.7 Summary of literature review

Beef producers are constantly seeking strategies to reduce feed and labour costs in beef cow-calf operations to maximise profit. Extensive grazing systems can reduce the labour and machinery costs associated with harvesting, storage and transportation of feed to the animal pens and manure removal from the pens. When compared to traditional drylot feeding system, extensive winter grazing strategies such as swath grazing cool season annuals such as barley (*Hordeum vulgare*) has been proven to reduce production and labor costs in a cow-calf operation. Recently, with the introduction of corn (Zea mays) hybrids suited to western Canadian weather, there is an increased interest in the use of warm season annuals in extensive grazing systems. However, it is important to choose an appropriate planting date for both cool and warm season crops to ensure that the crops have an adequate nutrient composition to support the cows at the time of winter grazing. Apart from this, yearly variations in weather can significantly affect forage yield and nutrient composition, which in turn can influence the rumen metabolic parameters, cow performance and reproductive efficiency in extensive grazing systems.

It was hypothesized that winter grazing whole plant standing corn and swathed whole plant barley will have no impact on crop yield and agronomy, rumen metabolism, beef cow performance and system costs when compared to a drylot feeding system. The objectives of the current study were to evaluate and compare the forage biomass production, nutrient composition, cow performance, reproductive efficiency and system costs of (i) whole plant standing corn grazing, (ii) whole plant swathed barley grazing and (iii) drylot pen feeding during winter. The study also evaluated the effect of the forages used in the above 3 feeding systems on rumen metabolic parameters such as ruminalpH, short chain fatty acids and ammonia-N concentration.

3.0 EFFECT OF WINTER FEEDING SYSTEMS ON FORAGE YIELD, UTILIZATION AND QUALITY, BEEF COW PERFORMANCE, REPRODUCTIVE EFFICIENCY AND SYSTEM COSTS

3.1 Introduction

Optimising the balance between input costs per cow and the resulting animal performance can determine the success of a beef production system (DelCurto et al., 2000). Factors such as increasing feed and yardage costs has increased the demand to increase beef production within the physiological constraints of the environment, which is the biggest challenge faced by beef producers (DelCurto et al., 2000).

Rangeland resources are the most common and economic feeding alternatives to harvested and purchased feeds in cow-calf production systems (Vallentine, 2000). As such, nutritional requirements of grazing animals exceed those of animals in confinement due to increased maintenance energy requirements for prehension of forage and coping with environmental stresses such as wind or cold (Holechek et al., 1998). However, the increased expenses associated with feed harvest, storage and confined feeding in cow-calf operations can be minimised and appreciable economic returns may be achieved by implementing grazing strategies instead of feeding animals previously harvested stored forages in drylot pens (Kelln et al., 2011; Krause et al., 2013). Understanding this concept has motivated many beef producers in western Canada to switch from conventional drylot systems to extensive grazing systems during the winter months.

In pasture based production systems, ensuring forage availability throughout the grazing season is important in achieving production goals (Barnes et al., 2007). Small grain annual cereals planted in late summer can provide adequate forage for grazing in the fall and the following spring. In addition, annual forages are often preferred over stockpiled perennials because of their higher energy values (Barnes et al., 2007).

In western Canada, climatic conditions are more suited for growing cool season forages (Barnes et al., 2007; SMA, 2008) which can be preserved for winter grazing by swathing at the soft to mid dough stage, which also limits nutrient losses due to trampling and maturity (SMA, 2008). Swathing makes it easier for animals to prehend the forage under snow cover in winter (Baron et al., 2006). Studies by Aasen et al. (2004) reported that weathering resulting from precipitation and snow can reduce nutritive value of swathed spring cereals but the forage can still meet the requirements for mid-gestation cows.

Warm season crops, like corn (*Zea mays*), can generate a more even distribution of crop biomass and remain productive in late summer and fall (Barnes et al., 2007). Warm season crops are generally superior to late seeded spring cereals due to the higher energy content (Khorasani et al., 2001). However, biomass production is largely dependent on the environmental temperature which questions warm season crop suitability in the cooler Canadian provinces like Saskatchewan (SMA, 2010). The recent introduction of low heat unit corn hybrids better adapted to cooler growing conditions are being examined for wider use in extensive grazing systems in Saskatchewan (Lardner, 2002; SMA, 2010; Lardner et al., 2012).

However, there are limited studies evaluating the agronomics of cool and warm season annuals and their effect on cow and calf performance in relation to traditional drylot feeding systems. Therefore the objectives of this study is to compare three winter feeding systems, (i) grazing standing whole plant corn (SC); (ii) grazing swathed whole plant barley (SB) and (iii) feeding whole plant barley hay bales in drylot pens (BH) to (1) to evaluate biomass and nutritive value of the three forages over year; (2) to determine the effect of winter feeding system on beef cow performance and reproductive efficiency; and (3) to conduct an economic analysis of the winter systems.

3.2 Materials and methods

3.2.1 Study site and crop management

A 2 year research trial was conducted at the Western Beef Development Center's, Termuende Research Ranch near Lanigan, Saskatchewan, Canada (51°51 'N, 105°02 'W). Soil at the study site was comprised of a mixture of Oxbow Orthic Black and carbonated Oxbow soil with a loam texture (Saskatchewan Soil Survey, 1992).

A 12 ha field site was assigned to 1 of 2 field grazing treatments, either grazing standing whole plant corn (SC) or grazing swathed whole plant barley (SB). Each crop type was furthur subdivided into replicate (n=2) 3-ha paddocks, using high tensile electric fences. In spring each year, 6-ha of corn (*Zea mays* cv. DKC 26-25) was seeded at the rate of 75,000 seeds/ha on June 7, 2012 and May 24, 2013 and 6 ha of barley (*Hordeum vulgare* cv. Ranger) was seeded at the rate of 108 kg/ha on June 8, 2012 and June 6, 2013. The corn and barley received 134.5 and 22.7 kg/ha, respectively of actual N fertilizer at the time of seeding. Weed control was managed pre-emergence in corn using Round Up at 1 L/ha applied mid June in both years and barley received Grow BF mid July 2012 and tank mix of Refine/Perimeter/Axial BIA in June 2013. Whole plant barley was harvested in August for swathed barley grazing at soft dough stage, while whole plant corn continued growth in September.

The barley hay (cv. Ranger) for drylot treatment (BH) was grown similar to swathed barley in the SB system at an adjacent location. The barley crop was swathed and then baled into large round hay bales (598 ± 48 kg) using a New Holland BR780 round baler on August 10, 2012 and August 20, 2013.

3.2.2 Estimation of forage biomass and nutritive value

Estimated forage biomass per ha for corn and barley treatments was calculated by measuring forage dry matter (DM) production per unit length of row for corn and unit area for barley. In September each year, forage samples were collected to determine total forage biomass and forage quality. Prior to swathing the barley in SB system, 25 0.25 - m^2 quadrat clips were taken in each replicate barley paddock to estimate DM yield per hectare. Dry matter yield in SC system was determined by sampling and weighing forage from 5 5.4 × 0.8 - m lengths of row in each replicate paddock and 5 sub-samples were collected for estimates of dry matter and forage quality. Dry matter yield of barley was also determined pre-graze by randomly weighing, 25 3 × 1 - m lengths of whole plant barley swath using a portable platform scale and in addition 5 sub-samples were collected to estimate dry matter and forage quality. All barley hay bales in BH system were weighed prior to feeding and 25 core samples from 8 random bales were taken using a 46 cm power-driven hay probe to estimate dry matter and forage quality.

Composite forage samples were collected for quality estimation from all systems every 21 d from the start and end of trial in each study year. Samples were collected by randomly selecting 1) 5 corn plants from each paddock cut 5cm above ground; 2) 5 grab samples of swathed whole plant barley; and 3) 5 core samples from each barley hay bale.

All samples were placed in a forced air oven at 55˚C for 72 h to determine DM content. Samples were then ground to pass through a 1-mm screen using a Thomas-Wiley mill (Model 4, Thomas Scientific, Swedesboro, NJ, USA), then labeled and stored in airtight sealer bags. Duplicate samples were then analyzed for crude protein (CP), total digestible nutrients (TDN), acid detergent fibre (ADF), neutral detergent fibre (NDF), Ca and P content. Crude protein was determined by the Kjehldahl N technique (method #984.13; AOAC 2000). Forage TDN was calculated according to the Adams (1995) equation. Acid detergent fibre (ADF) was analyzed following the method # 973.18 (AOAC, 2012). Neutral detergent fibre (NDF) was analyzed according to the procedure of Van Soest et al. (1991), with the inclusion of alpha amylase and sodium sulfite using an ANKOM TM200 fiber analyzer (ANKOM Technology, Fairport, NY). Calcium and phosphorus were determined following the method # 985.01 (AOAC 2000).

3.2.3 Estimation of dry matter intake and forage utilization

Dry matter intake (DMI) was measured as percentage of forage DM disappearance using a modified ‘pre- and post-graze technique’ previously described by Jasmer and Holechek (1984). This technique involves weighing a predetermined number of ungrazed plant units (leaf, twig, stem or a distinct plant part) from an fixed area in the field, then allowing animals to graze for a defined time, followed by weighing the same number of grazed plant units from that area in the field (Jasmer and Holechek, 1984). Utilization was calculated by subtracting average DM weight of forage post-grazing from average DM weight of forage pre-grazing and dividing it by the average weight per plant unit pre-grazing, expressed as percentage (Jasmer and Holechek, 1984). Total DMI was calculated by multiplying the difference in the average weight per forage unit pre and post-grazing in a unit area with the total area units grazed.

Determination of DM of post-grazed forage residues in field paddocks and drylot pens, was estimated using the same technique in spring after removing any faecal matter and foreign debris. To determine post-graze weight of remaining corn residue, 50 1.0 - m^2 quadrats at random locations were weighed in each replicate paddock and 5 sub-samples were collected to estimate DM content. To determine post-graze weight of swathed barley residue, 25 3 × 1- m lengths of swath were weighed using a portable platform scale and 5 sub-samples were collected for determining forage dry matter. Barley hay residue post grazing was determined by weighing all remaining bale residue using the same technique and any manure or foreign debris not associated with forage and grazing was removed. Also, 5 sub-samples were collected for estimation of forage DM percentage.

Forage intake was calculated according to the following equation (Jasmer and Holechek, 1984; Kelln et al., 2011).

Equation 3.1 Forage DMI (kg/cow/d) = (kg of DM/P allocated – kg of DM/P residual) / (n/p)

Where, P = 3-d feeding period, n = 10 (number of cows per experimental unit)

Equation 3.2 Utilization (%) = (Post-graze weight/Pre-graze weight) × 100

3.2.4 Grazing animal management

Each year 60 dry, pregnant multiparous Black Angus cows stratified by BW (658.2 ± 15 kg) were randomly allocated to 1 of 3 replicated (n = 2) winter feeding systems: (1) grazing standing whole plant corn (SC); (2) grazing swathed whole plant barley (SB) in field paddocks or (3) feeding whole plant barley hay bales in drylot pens (BH).

Cows were allocated forage based on forage nutrient density and environmental conditions in accordance with the NRC (2000) beef model as predicted by Cow Bytes ration balancing program (Alberta Agriculture and Rural Development 2011; Version 5.31). Cows were managed on winter systems for 77 d (9 November 2012 to 25 January 2013) in yr 1 and 78 d (24 October 2013 to 9 January 2014) in yr 2.

The cows were allowed controlled access to the standing corn and swathed barley on a 3 to 4 d basis using portable electric fences. Back-grazing was allowed, but cows were observed to spend most of their grazing time in recently allocated areas of pasture (Van De Kerckhove et al., 2011). All cows had *ad libitum* access to a commercial 2:1 mineral supplement (11.5% Ca, 10% P, 1% Mg, 5.8% Na, 200 ppm I, 4900 ppm Fe, 2000 ppm Cu, 5000 ppm Mn, 5000 ppm Zn, 20 ppm Co, 50 ppm Fl, 500000 IU/kg Vitamin A (min), 50000 IU/kg Vitamin D3 (min), 2500 IU/kg Vitamin E (min) (Right Now® Bronze, Cargill Nutrition) and cobalt iodised salt block. Water was provided in insulated portable troughs to each SC and SB group of animals and two portable wind breaks and bedding were provided in each replicate paddock.

Cows in the BH system were housed in two adjacent outdoor drylot pens (50 × 120 m) surrounded by wooden slatted fences located at the Termuende Research Ranch at about 1 km away from the research field site. Each pen contained an open-faced shed, a heated water bowl, a round bale feeder and cows had *ad libitum* access to a mineral supplement (Right Now® Bronze, Cargill Nutrition) and cobalt iodised salt block similar to cows in field paddocks. Each pen was also provided with a round bale feeder, which was replenished with a new hay bale every 3 to 4 days. All cows were managed according to the Canadian Council of Animal Care (CCAC, 2009).

Cow performance was determined by measuring BW, BCS and subcutaneous body fat thickness. Body weight was measured over 2 consecutive d at start and end of trial and every 21 d prior to feeding to avoid the effects of rumen fill on live body weight. Body weight was adjusted for conceptus weight and associated fluids using the following equation (NRC, 2000).

Equation 3.3 Conceptus weight (kg) = $(CBW*0.01828)*e^{[(0.02*t)-(1.43e\text{-}005*t*t)]}$

Where, CBW = calf weight at birth and t = days of pregnancy.

Body condition score (BCS) and subcutaneous body fat thickness were measured at start and end of the study (Schröder and Staufenbiel, 2006) by an experienced technician using a scale of 1 to 5 (1 = emaciated to 5 = grossly fat; Lowman et al. (1976). Body fat thickness was determined using ultrasonography between the 12^{th} and 13^{th} rib (site for 'grade fat') and rump fat (hip or thurl) using the Echo Camera SSD-500 diagnostic real-time ultrasound unit (Overseas Monitor Corporation Ltd., Richmond, BC, Canada) equipped with a UST 5044-17-cm, 3.5 MHz linear array transducer.

All cows were diagnosed for pregnancy prior to start of trial to ensure all animals were pregnant. Reproductive data collection included cow BW at calving, calf birth date, calf birth BW (within 24 h), calving span, calving pattern and calving rate. To determine the calving pattern the calving season each year was divided into 4 calving cycles of equal duration (1 to 20 d, 21 to 41 d, 42 to 62 d, 63 to 83 d) and the first d of calving was considered as d 1 of the calving cycle (Krause et al., 2013).

Following the winter grazing period, the cows were group fed a range pellet at 2 kg/cow/d (13% CP) and barley hay (13.1% CP, 42% ADF, 64.6% NDF in yr 1; 8.2% CP, 44.2% ADF and 65.9% NDF in yr 2) to meet nutrient requirements until adequate pasture growth was available in the spring. Cows were managed as a single group while on summer pasture and during the breeding season until the following winter period.

3.2.5 Statistical analysis

Statistical analysis was conducted using the Proc Mixed procedure of SAS (SAS version 9.2; SAS Inc., Cary, NC). The fixed effects were treatment, year and the interaction between treatment and year. Each replicate paddock or drylot pen was the experimental unit for a total of 12 experimental units over the 2-yr study. The PROC UNIVARIATE procedure of SAS was used to determine if data is normally, identically, and independently distributed (NIID).

Body condition score was analyzed for both years using the PROC Glimmix procedure of SAS (9.4) Means were separated using Tukey's multi-treatment comparison method (Saxton, 1998) and differences were considered significant when $P < 0.05$ and trends were discussed when $P < 0.10$.

3.2.6 Economic analysis

An economic analysis was conducted to determine winter feeding system costs (\$/head/d). Total crop production costs were calculated as the sum of crop production costs, yardage costs and other direct costs (bedding, medicine and veterinary services). The cost per cow per d can be calculated by dividing total crop production costs per ha by the number of cow grazing days per ha (Lardner et al., 2012).

Crop production costs were calculated using actual costs incurred, suggested retail prices and published custom rates from the Saskatchewan Ministry of Agriculture's Farm Machinery Rental, Custom and Rate Guide (SMA, 2014-15). Labour was valued at \$18/h, taking into consideration the approximate time spent for feeding, watering, bedding and checking cows each year. Yardage costs (unpaid labour and depreciation) were determined based on the calculated rates from cow-calf cost of production analysis (Larson, 2013). Land rental rate of $40/ha was included as an opportunity cost of the land when rented out to a local producer.

3.3 RESULTS AND DISCUSSION

3.3.1 Weather data

Daily mean temperatures (°C) and monthly precipitation (mm) were obtained from May 2012 to February 2014 at the Termuende Research Ranch Benchmark Site meteorological station (Appendix C; Figures C.1 and C.2). Long term (1981-2010) monthly averages for temperature (°C) and information on total precipitation and snow (cm) were obtained from the Environment Canada, Climate data online website (www.climate.weatheroffice.gc.ca) for Watrous, Saskatchewan, which is the closest weather station to the research study site.

Compared to the 30-yr average, mean monthly temperature increased by 1.5 °C in yr 1 (2012-13) and decreased by 2 °C in yr 2 (2013-14) in the month of July, for the Lanigan area. But mean temperature increased about 2 °C in September of yr 2 compared to yr 1 and 30 yr average (Figure C. 1). Temperature data from the weather station in Termuende Research Ranch, Lanigan showed that on a particular day in August 2013 (yr 2), night temperature dropped to a minimum of 0 °C. However, the duration of time the temperature was at this level is unknown, as only minimum and maximum temperatures are recorded at the weather station. Low environmental temperatures (< 0°C) during vegetative growth can be detrimental to the plant especially if frost occurs at the reproductive stage of the plant (Frederiks et al., 2012; Barlow et al., 2015). St-Pierre et al. (1983) observed that incidence of frost decreased fibre and mineral levels in corn silage. There was reduced feed utilization and apparent dry matter digestibility in lactating dairy cows fed on a diet comprising of 70% corn silage, as a result of the changes in plant nutrient composition at the milk and dough stages due to frost (St-Pierre et al., 1983). Frost damage after head emergence is difficult to assess, since the damaged crop heads may appear normal from outside (Frederiks et al., 2015). However, frost damage during grain fill can constrict the attachment between grain and ear, resulting in increased number of screenings in the harvested crops of wheat and barley (Cromey et al., 1998; Frederiks et al., 2015). However, overall the interpretation of temperature data for both years suggests that summer in yr 1 was warmer than yr two.

3.3.2 Forage biomass production and utilisation

Forage biomass and utilization is summarized in Table 3.1. Coleman (1992) suggested that the minimum biomass of 2 T/ha is required to support efficient grazing and forage apprehension through snow during winter months. In the current study, whole plant standing corn (SC) and swathed barley (SB) produced more than adequate biomass required to support grazing by beef cows. Whole plant standing corn DM yield was greater ($P < 0.01$) compared to barley averaged over 2 years. Higher DM yield of corn compared to barley was previously reported in another study on extensive winter grazing systems in Alberta (Baron et al., 2014).

Forage biomass and nutrient composition is influenced by plant species, genotype within species, stage of harvest, weather and other environmental conditions (Baron et al., 2012). There was a trend ($P = 0.06$) observed for forage yield to be lower in yr 1 compared to yr 2 (Table 3.1). Considering the fact that total rain received in yr 2 was lesser compared to yr 1 (Table C.2), the higher forage yield in yr 2 may be the result of delayed planting of corn and early harvesting of barley in yr 1, potentially leading to a reduced number of CHU (Corn heat units) for corn and GDD (growing degree day) for barley during the growing season in yr 1 compared to yr 2 (Appendix A. 1) (Baron et al., 2012; Ning et al., 2014; Rutto et al., 2014).

Table 3.1 Estimated forage biomass and utilization over 2 yr

Item	Treatment[1]			SEM	Year		SEM	*P*- value[2]		
	SC	SB	BH		1	2		Trt	Yr	Trt × Yr
Available forage, T/ha										
Wet yield	45.6a	39.2b	-	1.06	39.7	45.2	1.06	0.01	0.02	0.90
Dry yield	11.8a	7.9b	-	0.51	9.0	10.7	0.51	<0.01	0.06	0.30
DM, %	25.4a	20.2b	-	0.41	22.4	23.1	0.41	<0.01	0.15	0.06
Dry residual forage, T/ha	5.4a	2.9b	-	0.19	3.7	4.6	0.19	<0.01	0.03	0.32
Utilization, %	52.2c	63.9b	84.4a	1.60	69.3	64.4	1.50	<0.01	<0.01	0.11

[1]SC = grazing whole plant standing corn in field paddocks; SB = grazing whole plant swathed barley in field paddocks; BH = round bale barley hay fed in drylot pens
[2]Trt = treatment effects; Yr = year effects; Trt × Yr = treatment by year interaction
[a-c]Within a row means with different letter differ ($P < 0.05$)
SEM = standard error of the mean

According to Entz et al. (2002) forages cultivated for grazing can be planted at a later date compared to those used for grain production. Producers may require a later seeding date also in certain situations such as heavy rainfall in the spring (Baron et al., 2006). However, the selection of planting date can have a significant impact on forage yield or nutritive value of small grain forages such as oat, barley, rye and triticale at the time of harvest (Baron et al., 2012). Several studies have indicated reduced grain yield in small grain cereals with later planting date compared to an early spring planting dates (Juskiw and Helm, 2003; May et al., 2004; Baron et al., 2006). Baron et al. (2012) observed a linear decline (35 to 39%) in the yield of AC - Lacombe and Vivar varieties of barley with each wk delay in planting for 7 consecutive wk from mid-May to late June. Kibite et al. (2002) also observed a reduction in forage yield by 35% in oat and barley from early May to mid-June planting dates. However with similar planting dates, May et al. (2007) failed to observe any reduction in barley yield in Saskatchewan.

Nielsen et al. (2002) observed that the time and thermal requirement to reach the black layer in corn is reduced with late seeding dates. A study was conducted at University of Minnesota to evaluate corn yield with differing planting dates delayed from 0 wk, 2 wk and 4 wk. It was found that a 2 wk delay in planting date had no effect on grain yield (Van Roekel and Coulter, 2011), however grain yield was reduced by 15% when planting date was delayed by 4 weeks.

Utilization of the 3 forages was different ($P < 0.01$) between the winter feeding systems (Table 3.1). Cows housed in drylot pens (BH) had the greatest ($P < 0.01$) forage utilization compared to the field grazing systems (SC, SB). Limitations to feed accessibility resulting from snow, wind, precipitation and low temperatures can be more pronounced in field paddocks compared to drylot pens, which can negatively affect feed utilization (Dharmasiri Gamage, 2014). The cows grazing whole plant corn were the least efficient ($P < 0.01$) for forage utilization among the 3 winter grazing systems. The preferential refusal for consuming corn stalks by cows was observed in the SC treatment, which might have resulted in the reduced utilization of the whole corn plant (Myers and Underwood, 1992; Meyer et al., 2009).

Greater ($P < 0.01$) utilization of forage was observed in yr 1 study compared to yr 2 (Table 3.1). Comparatively lower forage availability as a result of lower forage yield (Table 3.1) and better nutrient quality of forages (Table 3.2) might have limited preferential selection by the cows in yr 1, resulting in improved forage utilization.

3.3.3 Forage quality

Chemical composition of forages differed ($P < 0.01$) between winter feeding systems (Table. 3.2). Whole plant corn was higher ($P < 0.01$) in energy (TDN) but lower ($P < 0.01$) in CP, ADF, NDF, lignin and minerals, when compared to barley in SB and BH systems. Forage composition is subject to change with year to year climatic variation, stage of plant growth at harvest, over winter weathering and plant type (Aasen et al., 2004). The differences in nutrient levels of barley forage in SB and BH may have resulted from the early harvesting of the barley hay at baling (BH) to ensure adequate moisture at storage, thus preventing mold growth and loss of nutritive value (Martinson et al., 2011). Nutrient losses due to leaf loss and weathering is more pronounced in swath grazing whereas baling forage ensures a better preservation of nutrients which might have further contributed to a difference in forage quality between SB and BH systems in the current study (Baron et al., 2006; Kelln et al., 2011).

Significant interactions ($P < 0.01$) between treatment (SC, SB and BH) and yr of study were observed for all forage quality parameters except TDN content. Differences in planting

Table 3.2 Chemical composition of forages in winter feeding systems (%)

Item	Treatment[1]						SEM	*P*- value[2]		
	SC		SB		BH					
	Yr 1	Yr 2	Yr 1	Yr 2	Yr 1	Yr 2		Trt	Yr	Trt × Yr
DM	45.7c	56.5bc	64.6ab	63.3ab	77.8	77.5	3.11	<0.01	0.27	0.17
CP	9.5c	9.0d	13.2a	10.0b	13.1a	8.2e	0.07	<0.01	<0.01	<0.01
ADF	30.1c	25.1d	38.5b	36.2b	42.0a	44.2a	0.67	<0.01	<0.01	<0.01
NDF	54.7b	45.8c	58.4b	56.3b	64.6a	65.9a	0.99	<0.01	<0.01	<0.01
TDN	66.1ab	69.8a	56.8c	61.9b	53.2c	55.2c	0.75	<0.01	<0.01	0.21
Lignin	3.4d	3.0d	4.8c	5.0c	5.8b	6.8a	0.18	<0.01	0.32	<0.01
Ca	0.2bc	0.2c	0.5a	0.3b	0.5a	0.3b	0.02	<0.01	<0.01	<0.01
P	0.2b	0.2b	0.3a	0.2b	0.3a	0.2c	0.01	<0.01	<0.01	<0.01

[1]SC = grazing whole plant standing corn in field paddocks; SB = grazing whole plant swathed barley in field paddocks; BH = round bale barley hay fed in drylot pens

[2]Trt = treatment effects; Yr = year effects; Trt × Yr = treatment by year interaction

[a-c]Within a row means with different letter differ ($P < 0.05$)

SEM = standard error of the mean

dates for corn and harvesting dates for swathed barley in SB treatment and both planting and harvest dates of baled barley hay (Appendix A.1), may have resulted in differences in nutrient composition between yr 1 and yr 2 (Table 3.2). There is sufficient evidence for advanced maturity to result in variation of nutrient composition of forages (Jung and Allen, 1995; Rosser et al., 2013). Increased fiber and lignin concentrations were observed by Khorasani et al. (1997) when annual cereals advanced in maturity from boot stage to soft dough stage. In the current study, corn (SC) was seeded 14 d earlier in yr 2 compared to yr 1 and barley (SB) was harvested 8 d later in yr 2 than in yr one. There was also a difference of 14 d in crop maturity when barley hay was harvested (BH) in yr 2 compared to yr one. The higher lignin concentration of swathed whole plant barley (4.8 and 5.0% in yr 1 and yr 2, respectively; $P > 0.05$) and barley hay used in drylot pens (5.8 and 6.8% in yr 1 and yr 2 respectively) may indicate a more mature forage in yr 2 compared to yr one. However, contrary to what was observed in barley forage, lignin concentration of corn was lower in yr 2 than yr 1 (3.4 and 3.0% in yr 1 and yr 2, respectively; $P > 0.05$).

The early frost in August 2013 may also suggest a reason for observed differences in nutrient composition (Frederiks et al., 2012). St-Pierre et al. (1983) observed that incidence of frost decreased fibre and mineral levels in corn silage and reported a reduced feed utilization and apparent dry matter digestibility in lactating dairy cows, resulting from changes in plant nutrient composition due to frost (St-Pierre et al., 1983).

In the current study, across all systems, the CP content in forages decreased in yr 2 ($P < 0.01$). The decrease in CP was greatest for barley hay (BH) (13.1 and 8.2 %) and least for corn (9.5 and 9 %), between years as forage CP levels were found to decline with increasing forage maturity (Kilcher, 1981; Wiersma et al., 1993). In earlier work by Weaver et al. (1978), corn leaf

CP content showed a decline with later harvesting dates, but did not show any significant change in quality for other plant structures. Volesky et al. (2002) observed a decline of forage CP content from 10.6 (September) to 5.7 % (February) at the end of a 2 yr study, where calves were winter grazed on standing stockpiled forages. These study results suggest for the possibility of declining forage CP levels with advanced maturity of forages in yr 2 of the current study.

Swathed whole plant barley (SB) and barley hay forage (BH) fiber (ADF and NDF) levels were not different ($P > 0.05$) between the two years (Table 3.2). However, ADF and NDF levels in corn were found to decrease ($P < 0.01$) from yr 1 to yr two. According to Collar et al. (2004), the fibre content (ADF and NDF) is found to increase until grain development in small grain species such as wheat. But as the plant matures further the increase in non-fibrous carbohydrates or starch in the grain can compensate for any increased fibre levels in the stem and leaves (Khorasani et al., 1997; Tolera et al., 1998), thereby diluting total fibre content of the whole plant (Hunt et al., 1989; Collar et al., 2004). Wiersma et al. (1993) indicated an average decrease of 7.6% for NDF and 4.4% for ADF as corn grain matured from soft dough stage to half milk line. Kim et al. (2001) also observed lower ADF and NDF percentages in corn hybrids from an early planting date (April 15) compared to a late planting date (May 15). In addition, weathering or loss of leaves due to senescence can also result in decreased levels of fibre in the whole plant (Weaver et al., 1978). Finally, frost conditions were also found to have a negative impact on fibre levels in corn silage (St-Pierre et al., 1983).

Whole plant lignin concentration was found to increase with advancing maturity of the crop (Nelson and Moser, 1994). However no differences ($P > 0.05$) were detected for lignin content of whole plant corn (SC) and swathed barley (SB) forage with increased crop maturity in yr 2 (Table 3.2). However lignin concentration increased from 5.8% in yr 1 to 6.8% in yr 2 in barley hay forage (BH).

Total digestible nutrient (TDN) level did not differ ($P > 0.05$) between yr for corn (SC) or barley hay (BH) (Table 3.2). However, TDN level was higher ($P < 0.01$) for swathed barley (SB) in yr 2 compared to year one. Burken et al. (2013) observed increased energy levels (TDN) with increasing grain concentrations in corn forage. In cool season annuals, such as wheat and triticale, Collar et al. (2004) observed an initial decrease in energy followed by an increase with the advancing stages of maturity. Being higher in maturity in yr 2, high energy (TDN) levels were expected in all forages (SC, SB, BH), but it was only observed in swathed barley forage (SB) in the current study. Factors such as weathering (Aasen et al., 2004) or grain loss (Lawles et al., 2012) may have resulted in the absence of yr differences in energy content of corn (SC) and barley hay (BH) forage.

Calcium and P content of corn did not differ ($P > 0.05$) in SC between yr in the current study (Table 3.2). However, swathed barley and barley hay showed a decline in Ca and P concentration from yr 1 to yr two. Mineral concentration has been found to increase in the initial stages of plant development and then decrease with advanced maturity stages (Weaver et al., 1978; Kilcher, 1981). Levels of Ca and other minerals are also susceptible to decline with crop damage resulting from frost (St-Pierre et al., 1983). These suggested factors may have influenced the reduction in Ca and P content in both barley forages (SB, BH) in the second yr of study. In addition to these factors, an inverse relation between nutrient composition and forage yield was previously observed by Streeter et al. (1966), who investigated the effect of harvest date and method of storage on the nutritive value of forages over two years. The authors observed low ($P < 0.01$) levels of Ca and P corresponding to a higher forage yield in second yr of study compared to the first yr. Similar to this, a tendency ($P = 0.06$) for higher forage biomass in the current study, corresponded to a lower percent Ca and P in swathed barley (SB) and barley hay (BH).

However, despite the variations between treatment and yr of study, the nutrient (CP, TDN) and mineral (Ca, P) composition of forages in all winter systems were satisfactory to meet the requirements of dry pregnant cows in the second trimester of pregnancy (NRC, 2000).

3.3.4 Animal performance

Measurements of live BW changes, body fat thickness, BCS and estimated feed intake have been considered as effective indicators for comparison of the effect of winter feeding systems (Krause et al., 2013; Dharmasiri Gamage, 2014). In the current study, the cows managed in 3 wintering systems did not differ ($P > 0.05$) for initial BW, final BW, BW change, initial and final rib and rump fat thickness, changes in rump fat thickness or ADG but did differ ($P < 0.05$) for changes in rib fat and DMI (Table 3.3). Averaged over 2 yr, the increase in rib fat was greater ($P = 0.02$) for SC cows compared to SB cows (1.6 vs 0.3 mm, respectively). Changes in rib fat were not different ($P > 0.05$) between SC and BH system and SB and BH system. For measurements such as final cow BW, BW change, final rib fat thickness and average daily gain, there was a tendency ($P \leq 0.1$) for SC cows to have maximum values followed by SB and then BH (Table 3.3). The cows in SC also tended to have higher ($P = 0.1$) values for final rump fat and increase in rump fat thickness compared to SB and BH systems. In contrast, corn graze cows had lower ($P < 0.01$) estimated DMI compared to swath barley and barley hay cows which did not differ ($P > 0.05$) (9.1, 14.3 and 13.0 kg/d, respectively).

Voluntary feed intake in grazing ruminants is often limited by physical characteristics of plant species, preferential selection of plant species or plant parts by animals or by extremes in

Table 3.3 Effect of winter feeding system on beef cow performance

	Treatment[1]			SEM	Year		SEM	*P*- value[5]		
Item	SC	SB	BH		1	2		Trt	Yr	Trt × Yr
Cow BW[2], kg										
Initial	654.6	659.7	659.7	2.91	643.7	672.2	2.37	0.42	<0.01	0.33
Final	678.4	654.6	669.6	7.07	670.0	665.0	6.21	0.08	0.49	0.35
Change	23.8	-4.9	10	7.18	26.5	-7.2	5.92	0.09	<0.01	0.58
Pre – calving	746.4	726.7	727.0	20.32	737.7	729.0	18.9	0.10	0.25	0.61
Rib fat, mm										
Initial	4	4	3.7	0.45	3.8	4.0	0.36	0.88	0.62	0.62
Final	5.6	4.3	4.4	0.41	4.6	4.9	0.35	0.11	0.54	0.43
Change	1.6a	0.3b	0.7ab	0.27	0.9	0.9	0.24	0.02	0.95	0.34
Rump fat, mm										
Initial	3.5	3.8	3.3	0.45	3.2	3.8	0.37	0.75	0.24	0.99
Final	5.2	4.4	3.8	0.38	4.2	4.6	0.31	0.09	0.37	0.99
Change	1.7	0.6	0.5	0.36	1.1	0.8	0.3	0.10	0.55	0.96
ADG[3], kg d^{-1}	0.3	-0.1	0.1	0.09	0.3	-0.1	0.08	0.09	<0.01	0.60
DMI[4], kg d^{-1}	9.1b	14.3a	13.0a	0.71	11.8	12.5	0.58	<0.01	0.39	0.21

[1]SC = grazing whole plant standing corn in field paddocks; SB = grazing whole plant swathed barley in field paddocks; BH = round bale barley hay fed in drylot pens
[2]Cow BW was adjusted for conceptus weight gain
[3]ADG = Average daily gain
[4]DMI = Dry matter intake
[5]Trt = treatment effects; Yr = year effects; Trt× Yr = treatment by year interaction

environment temperatures (Allison, 1985; Ingvartsen and Andersen, 2000). Therefore, the efficiency of a grazing ruminant is often improved by increases in feed intake (Allison, 1985; Mertens, 1994). However, the cows grazing standing whole plant corn in the current study had numerically greater performance than cows grazing swathed barley or fed barley hay in maintaining BW, fat reserves and BCS, despite a significantly lower ($P < 0.01$) corn DMI.

In the western Canadian climatic conditions, available energy content is the most limiting factor in forage nutritive value. According to Crampton (1957), cattle fed solely on forages may consume nutrients in fixed proportion to the energy content of the plant. When the animal consumes feed to meet its energy requirements, it will normally meet the requirements for protein, Ca and phosphorus (Crampton, 1957). Feed intake was also found to decrease with increases in forage digestibility in high roughage rations fed to dairy cattle (Conrad et al., 1964). The energy (TDN) content (70%) of corn was higher relative to that measured in barley forage (59.3%; SB and 54.2%; BH). The interpretation of the intake results from the current study with the previously mentioned literature suggests that the corn cows were more efficient compared to SB and BH cows, in converting each unit of feed DM to net energy for maintenance and production.

Of the 3 winter feeding systems, barley swath grazing system (SB) was the only system where cows had a negative BW change (-4.9 kg), averaged over 2 years (Table 3.3). Yet, the barley hay fed in the BH system was lower in CP and TDN content in yr 2 and higher in fibre content (ADF, NDF) in both yrs compared to swathed barley grazed in the SB system (Table 3.2), suggesting barley hay was inferior to swathed barley (SB) in forage quality. However, several reasons can be attributed to the poor performance of cows in swath graze barley system. Firstly, cold environmental temperatures and potential difficulty in feed accessibility (Figures

C.1) may have reduced the efficiency of forage utilization by cows grazing swathed barley (Adams et al., 1994; Kelln et al., 2011). Increased snow depth and reduced visibility resulting from heavy snowfall can make it difficult for the cows to find and consume forages buried under the snow (Kelln et al., 2011). The cows managed in drylot pens in the BH system had direct access to forage in bale feeder. This difference is evident when comparing forage utilization, which shows that SB cows had a lower ($P < 0.01$) utilization compared to cows in the BH system (64 and 84 %, respectively) (Table 3.1). There is also a possibility for preferential sorting for barley grain heads by cows (DeVries et al., 2014) in the SB system, which can predispose them to lower ruminal pH (sub-acute ruminal acidosis), negatively affecting forage digestibility and intake (Stone, 2004; Plaizier et al., 2012). This can subsequently result in loss of BW and animal productivity (Owens et al., 1998).

No differences were observed for BCS between SC, SB and BH managed cows (Tables 3.4 and 3.5). Krause et al. (2013) in a study comparing drylot feeding (DL) with extensive grazing of oat (OAT) and pea residues (PEA), observed lower final BW, BW change and decreased rib fat in cows grazing PEA residue compared to cows grazing OAT residue, but failed to detect any difference in BCS between study animals. Similar to this, in another study evaluating supplementation strategy for cows grazing barley residue piles (Van De Kerckhove et al., 2011), even though the 100% barley grain supplemented cows lost 6.5 kg of BW ($P < 0.01$) during the experiment, no change ($P > 0.05$) was observed for cow BCS between 100% DDGS supplemented and barley grain supplemented cows. A minimum BW difference of 50 kg is required to detect a BCS change of 0.5, in a 0-5 scale system as reported by Lowman et al. (1976), and this may explain why in the current study no changes in BCS were detected between cows in the winter feeding systems and also suggests that cows managed in SC, SB and BH

Table 3.4 Effect of winter management system on body condition score (BCS) in yr 1 study

BCS	Treatment[1]			SEM	*P*-value
	SC	SB	BH		
Start of trial (% of cows)					
2	0.0	0.0	0.0	0.00	1.00
2.5	80.0	65.0	65.0	0.09	0.42
3	15.0	30.0	30.0	0.09	0.49
3.5	5.0	5.0	5.0	0.04	1.00
4	0.0	0.0	0.0	0.00	1.00
End of trial (% of cows)					
2	0.0	0.0	0.0	0.00	1.00
2.5	50.0	75.0	75.0	0.10	0.39
3	45.0	20.0	20.0	0.10	0.38
3.5	5.0	5.0	5.0	0.04	1.00
4	0.0	0.0	0.0	0.00	1.00
BCS change (% of cows)					
-0.5	5.0	20.0	20.0	0.06	0.50
0	60.0	70.0	70.0	0.10	0.62
0.5	25.0	10.0	10.0	0.09	0.55
1	5.0	0.0	0.0	0.03	1.00
1.5	5.0	0.0	0.0	0.03	1.00
Pre - calving (% of cows)					
2	0.0	0.0	0.0	0.00	1.00
2.5	21.0	55.0	35.0	0.10	0.25
3	26.0	30.0	60.0	0.10	0.21
3.5	42.0	10.0	5.0	0.08	0.14
4	11.0	5.0	0.0	0.05	0.83

[1]Treatment (Trt); SC = Cows grazed on whole plant standing corn; SB = Cows grazed on barley swaths; BH = Cows feeding barley hay in drylot pen

[a-c]Within a row means with different letter differ ($P < 0.05$)

SEM = standard error of the mean

Table 3.5 Effect of winter management system on body condition score (BCS) in yr 2 study

BCS	Treatment[1] SC	SB	BH	SEM	P-value
Start of trial (% of cows)					
2	0.0	0.0	0.0	0.00	1.00
2.5	75.0	75.0	75.0	0.07	0.58
3	20.0	20.0	25.0	0.06	0.71
3.5	5.0	5.0	0.0	0.03	1.00
4	0.0	0.0	0.0	0.00	1.00
End of trial (% of cows)					
2	0.0	0.0	5.0	0.01	1.00
2.5	65.0	65.0	55.0	0.08	0.50
3	30.0	25.0	20.0	0.07	0.37
3.5	5.0	10.0	20.0	0.04	0.71
4	0.0	0.0	0.0	0.00	1.00
BCS change (% of cows)					
-0.5	5.0	10.0	10.0	0.04	0.26
0	80.0	65.0	50.0	0.07	0.96
0.5	15.0	5.0	20.0	0.06	0.34
1	0.0	10.0	10.0	0.05	0.16
1.5	0.0	10.0	10.0	0.07	1.00
Pre - calving (% of cows)					
2	0.0	0.0	0.0	0.00	1.00
2.5	32.0	55.0	42.1	0.11	0.45
3	47.0	40.0	47.4	0.11	0.87
3.5	16.0	0.0	10.5	0.06	0.90
4	5.0	5.0	0.0	0.04	1.00

[1]Treatment (Trt); SC = Cows grazed on whole plant standing corn; SB = Cows grazed on barley swaths; BH = Cows feeding barley hay in drylot pen

[a-c]Within a row means with different letter differ ($P < 0.05$)

SEM = standard error of the mean

systems were successful in maintaining their body condition throughout the study period and further until calving.

A significant year effect ($P < 0.05$) was observed for certain performance measures for and average daily gain (Table 3.3). Cows entering the winter systems at the start of trial in yr 2 (2013) were heavier ($P < 0.01$) than cows in yr 1 (2012), which may be explained by the accumulation of body tissue with advancing cow age. An increase ($P < 0.01$) in BW with age was previously observed by Renquist et al. (2006) in multiparous beef cows. Despite being heavier at the start of the experiment, comparatively lower forage quality due to increased forage maturity of forage affected performance of cows managed in all 3 winter feeding systems (SC, SB and BH) in yr 2, as evident from the daily loss ($P < 0.01$) of 0.1 kg of cow BW in yr 2 (Table 3.3). However, body fat reserves such as rib and rump fat thickness (Table 3.3) and BCS (Tables 3.4 and 3.5) were found not to be affected ($P > 0.05$) by the year of study.

3.3.5 Reproductive performance

Reproductive performance data including calving rate, calf birth date, last calf born, length of calving span and calving pattern were not different ($P > 0.05$) between the cows managed in the 3 winter feeding systems ($P > 0.05$; Table 3.6). Cow BW did not differ ($P = 0.1$) between the treatments before calving (Table 3.5). This would suggest a compensatory weight gain following the grazing period where all cows were fed on a common diet consisting of processed barley hay (11% CP, 54% TDN) and a pre-calving pellet (13% CP). However, calf BW was greater (42.7 kg; $P < 0.01$) for cows grazing standing corn compared to cows grazing swathed barley (39.7 kg) or barley hay in pens (39.7 kg).

Table 3.6 Effect of the winter feeding system on cow reproductive performance

	Treatment[1]				Year			P – value[3]		
Item	SC	SB	BH	SEM	1	2	SEM	Trt	Yr	Trt ×Yr
Calving rate, % of total	92.5	92.5	97.5	3.93	95	93.3	3.29	0.58	0.71	0.58
Calf birth date, Julian date	109	107	110	4.44	102	116	3.63	0.88	0.03	0.64
Calf BW[2], kg	42.7a	39.7b	39.7b	0.42	40.7	40.7	0.35	<0.01	0.89	0.23
First calf born, Julian date	94ab	87b	95a	1.79	90	93	1.46	0.03	0.16	0.24
Last calf born, Julian date	134	134	135	7.60	129	140	6.21	0.99	0.26	0.25
Calving span, d	45.8	42.0	40.5	7.07	35.5	50.0	5.77	0.87	0.13	0.49
Calving pattern, % of total										
1 to 21 d	62.0	54.5	50.5	9.31	77.7	33.7	7.60	0.69	<0.01	0.61
22 to 42 d	21.5	30.8	25.5	10.40	17.2	34.7	8.49	0.82	0.20	0.91
43 to 63 d	10.8	15.0	21.0	8.12	5.2	26.0	6.60	0.69	0.07	0.66
64 to 84 d	5.5	0.0	2.8	3.55	0.0	5.5	2.90	0.58	0.23	0.58

[1]Treatment (Trt); SC = grazing whole plant standing corn in field paddocks; SB = grazing whole plant swathed barley in field paddocks; BH = round bale barley hay fed in drylot pens
[2]Calf birth body weight was recorded within 24 h of parturition
[3]Trt = treatment effects; Yr = year effects; Trt× Yr = treatment by year interaction
[a-c]Within a row means with different letter differ ($P < 0.05$)

There are studies which support the argument that a compromised maternal nutrition during early stages of gestation can negatively affect the performance of progeny (Wu et al., 2006). This is because myogenesis and adipogenesis takes place in the early stages of fetal development and inadequate maternal nutrition at this stage can result in the decrease in muscle fibre numbers leading to adverse effects in progeny performance (Du et al., 2010). Studies have reported superior reproductive performance in offspring from dams provided with a higher plane of nutrition compared to offspring from dams that are nutritionally challenged during pregnancy (Martin et al., 2007; Muñoz et al., 2009). Cow nutrient requirements are lowest in the early stages of pregnancy, but will increase considerably in the second and third trimester (Funston et al., 2010). According to Robinson (1977), about 75% of fetal growth occurs in the last 2 mo of gestation. Several studies have shown an improved progeny performance from dams on a better quality ration during late gestation (Martin et al., 2007; Funston et al., 2010; Mulliniks et al., 2013). However, cows in the current study were provided diets that readily met the requirements of a dry pregnant cow in the second trimester of pregnancy (NRC, 2000). This further suggests that the cows may have undergone a compensatory weight gain when fed a similar pre-calving ration after the winter grazing period. This may explain the inability to detect any differences in reproductive performance measures between cows in all systems except for calf birth BW and date of first calf born (Table 3.4).

Plane of nutrition during early stages of pregnancy were found to have variable effects on progeny birth weight (Muñoz et al., 2009; Funston et al., 2010). Standing whole plant corn has quality and structural advantages over barley forage, which can have an influence on progeny performance of cows in SC system. Corn was higher in energy (TDN) content compared to swathed barley and barley hay (70.0 vs 59.3 and 54.2 % for SC, SB and BH, respectively), which is the most important nutrient (Ensminger et al., 1990) that aids in preserving cow body reserves amidst extremely low temperatures (NRC. 2000). Corn stalks can also act as an effective wind barrier and stand up well above the snow making it easier for cows to access the forage during winter (Baron et al., 2003). Higher than average birth weights have been found to have a beneficial effect in reducing the incidence of calf mortality and post-natal disease (Funston et al., 2010), which suggests an increased probability of calf survival of calves born to cows grazing corn compared to calves born to cows grazing swathed barley (SB) or barley hay in drylot pens (BH).

Calving rate, calf BW and calving span were not affected ($P > 0.05$) by year of study. A significant effect of year was observed for calf birth date and percentage of total calves born in the first 21 d from start of calving. Birth date of calves born to cows in yr 1 of the study were 14 d earlier ($P = 0.03$), compared to calves born to cows in yr two (102 vs 116 d, respectively). Also, in the first 21 d of the calving season, cows gave birth to 77% of total calves born in yr 1, which was reduced to only 34% in yr 2. The yearly difference in climatic condition (Section 3.3.1) and forage quality (Section 3.3.3) might have contributed to this variation in calving pattern. According to Stevenson et al. (1997), later calving cows will also return to estrus later, which can subsequently cause a delay in conception and calving period. This suggests that a delay in calving in a particular year can have an impact on the calving pattern in the next year. Taking these aspects into consideration, it can be concluded that changes in forage quality and environmental conditions can have an effect on the calving pattern in winter feeding systems.

3.3.6 Economic analysis

The economic analysis associated with each winter feeding system included (i) fixed costs comprised of labour, fuel, equipment use, yardage, infrastructure and depreciation and

Table 3.7 Effect of different winter feeding systems on system economics

	Treatment[1]				Year			*P* – value[2]		
Item	SC	SB	BH	SEM	1	2	SEM	Trt	Yr	Trt × Yr
	……...\$ cow^{-1}d^{-1}………				…..\$ cow^{-1}d^{-1}…..					
Feed costs										
Forage costs	1.20	1.14	1.34	0.065	1.27	1.18	0.053	0.18	0.25	0.14
Mineral and salt	0.10	0.10	0.09	0.004	0.1	0.09	0.004	0.10	0.51	0.22
Total feed costs	1.30	1.24	1.43	0.066	1.37	1.27	0.054	0.21	0.24	0.17
Other direct costs										
Bedding	0.05b	0.05b	0.08a	0.005	0.06	0.06	0.005	<0.01	0.05	0.28
Total other direct costs	0.05b	0.05b	0.08a	0.005	0.06	0.06	0.005	<0.01	0.05	0.28
Yardage costs										
Machinery costs (including fuel)	0.30b	0.30b	0.67a	0.028	0.44	0.41	0.025	<0.01	0.20	0.06
Labour	0.32	0.32	0.27	0.012	0.31	0.30	0.010	0.05	0.30	0.11
Yardage	0.05	0.05	0.10	0.012	0.31	0.30	0.010			
Depreciation	0.04b	0.04b	0.17a	0.006	0.08	0.08	0.006	<0.01	0.55	0.90
Manure Cleaning	0.00	0.00	0.04	0.006	0.08	0.08	0.006			
Total yardage costs	0.71b	0.71b	1.25a	0.044	0.91	0.87	0.039	<0.01	0.33	0.10
Total production costs	2.06b	2.00b	2.75a	0.097	2.34	2.19	0.081	<0.01	0.21	0.10

[1]Treatment (Trt); SC = grazing whole plant standing corn in field paddocks; SB = grazing whole plant swathed barley in field paddocks; BH = round bale barley hay fed in drylot pens

[2]Trt = treatment effects; Yr = year effects; Trt × Yr = treatment by year interaction

[a-c]Within a row means with different letter differ ($P < 0.05$)

SEM = standard error of the mean

(ii) variable costs comprised of forage costs, bedding, minerals and salt (Krause et al., 2013). The costs were estimated on a per cow per day basis using feeding records from the 77 d and 78 d trials in yr 1 and yr 2, respectively (Table 3.7).

Mineral was priced at \$1.21 per kg and salt at \$5.25 per block. Labour was charged at \$18.00 per hour. The average production costs over 2 yr were \$2.06, \$2.00 and \$2.75 cow/d for SC, SB and BH systems, respectively. Of the 3 winter feeding systems, total production costs for cows grazing whole plant corn and swathed barley were lower ($P < 0.01$) compared to cows consuming barley hay in drylot pens (Table 3.8). However, production costs for cows grazing corn and swathed barley were not different ($P > 0.05$). Compared to the drylot system (BH), total system costs were 25 or 27% lower ($P < 0.01$) for corn graze and swath barley graze systems, respectively.

The average cost for bedding was higher ($P < 0.01$) for BH system compared to SC and SB systems. In contrast, bedding costs were higher in a field residue grazing system compared to a drylot system in a study of winter feeding systems by Krause et al. (2013). The authors argued that this increase might have resulted from increased bedding provided in the field grazing systems, since cows were exposed to colder environmental conditions in the field compared to the drylot pen. A study by Dharmasiri Gamage (2014) detected no difference in bedding expenses between a field forage grazing system and drylot system. Total yardage costs were higher for the BH system ($P < 0.01$) compared to SC and SB systems. The increased ($P < 0.01$) costs associated with machinery and fuel, manure removal and depreciation resulted in increased yardage costs for the BH system. The drylot system (BH) involved additional labour and equipment costs associated with moving bales to round bale feeders in the pens every 3 d and costs associated with manure removal from the pens, which is similar to the findings by Kelln et al. (2012). Yardage costs for an industry field grazing system would be expected to be lower than the costs in the current study since research studies involve small number of cows in replicate groups and hence the labour and equipment costs which are fixed, are borne by fewer animals.

The calculated total production costs for the current study do not include costs for hauling water to cows in the winter feeding systems. Water was provided every 2 d in water troughs in all field paddocks. The equipment and labour charges for watering averaged $0.67 per day. In contrast, cows in the drylot treatment consumed water from a heated water bowl located in each drylot pen, and hence did not require any additional labour or equipment costs to provide water. The infrastructure expense for water bowls is included in the depreciation calculation for the drylot treatment. Managing animals in replicated groups, intensive data collection and lower sample size in research trials can inflate estimated total production costs, especially labour and equipment when compared to an industry scenario (Krause, 2013). For this reason water hauling charges are considered separately as additional costs, such that the cost estimates are more reflective of a practical industry situation.

Overall, the field grazing systems (SC, SB) had lower system costs compared to the conventional drylot system in the current study, which agrees with previous results comparing the economics of extensive grazing strategies to drylot pen feeding (Kaliel and Kotowich, 2002; Kelln et al., 2011; Krause, 2013). However, the lower utilization of forages in the field grazing systems (52.2% and 63.9% in SC and SB), can have a profound influence in increasing the feed costs in these feeding systems. Therefore, management strategies to increase feed utilization in SC and SB may decrease the feed costs further, consequently leading to a decrease in the overall production costs.

3.3.7 Summary

Adoption of extensive winter grazing systems such as grazing whole plant standing corn or swathed whole plant barley can reduce labour and production costs during winter months, compared to feeding barley hay bales in drylot pens. However, environmental growing conditions can have an impact on annual forage yield and nutritive value. Winter month sub-zero temperatures during grazing periods can also negatively impact cow performance. The unpredictability of daily environmental temperatures during winter in western Canada emphasizes the possible risk a producer might undertake while adopting extensive grazing systems. At the same time, effective management practices can reduce the adverse effects of weather, without negatively affecting cow performance or reproductive efficiency. Another advantage of extensive grazing systems is the increased efficiency by which manure nutrients are retained in the soil on the grazing site which can improve subsequent crop production in the pasture and may cut down the cost of commercial fertilizers. Furthur research is required to evaluate the long term benefits of extensive grazing programs in improving animal performance, soil nutrient levels and thus promoting substantial economic returns for the western Canadian beef producer.

4.0 THE EFFECT OF FORAGE TYPE ON RUMINAL PH AND FERMENTATION CHARACTERISTICS

4.1 INTRODUCTION

Ruminal health has a crucial role on the health and performance of a beef animal (Archimède et al., 1997). Rumen fermentation accounts for about 80% of dietary fibre digestion (Archimède et al., 1997) and provides 50 to 70% of the total amino acid supply (Polan, 1988). Therefore, optimization of ruminal fermentation can increase the efficiency of dietary fibre and carbohydrate digestion and utilization by the ruminal microbes, resulting in a greater supply of energy substrates and amino acids to the host animal (Calsamiglia et al., 2010; van Vuuren et al., 2012). Increased metabolic efficiency can potentially provide better profits to producers in terms of cow body weight and performance (Owens et al., 1998) and also minimize the environmental concerns arising from excreted nutrients (Oenema, 2006). The implications in maintaining ruminal pH at optimum levels has been extensively reviewed (Kleen et al., 2003; Plaizier et al., 2008). Low ruminal pH, resulting from the over consumption of highly fermentable carbohydrates can upset the rumen microbiome (Nagaraja and Titgemeyer, 2007), resulting in several health consequences (Schwaiger et al., 2013). When ruminal pH goes below the optimum threshold, it can lead to a disruption in the epithelial barrier function (Steele et al., 2009; Aschenbach et al., 2011) and reduced absorption of short chain fatty acids (SCFA) (Gabel et al., 2002). This may result in decreased fibre digestibility (Stone, 2004) and subsequent reduction in dry matter intake (DMI) (Plaizier et al., 2008), negatively affecting animal performance and efficiency (Owens et al., 1998). Much of the work pertaining to this aspect has been conducted in lactating dairy cows (Penner et al., 2010) and feedlot beef steers (Nagaraja and Titgemeyer, 2007). Beef cattle on feedlot diets are more susceptible to a drop in ruminal pH, as they are commonly fed a high energy grain diet to meet performance (gain) requirements. However, beef heifers grazing whole plant cereals are found to exhibit a preferential selection of plant parts such as grain and leaves (Rosser, 2014). Sorting for energy rich plant parts can predispose grazing cattle to metabolic conditions that can result in a low rumen pH, thus affecting their overall performance (DeVries et al., 2014). With the development of systems that enable continuous pH measurements (Dado and Allen, 1993; Penner et al., 2006); it is possible now to monitor between d and within d variations in ruminal pH that can provide researchers a better understanding of the physiological mechanisms associated with feed sorting in grazing livestock.

The ruminal environment for efficient microbial function is instinctively controlled by the host animal, by mechanisms such as adjusting the type and quantity of consumed feed, controlling ruminal contractions to increase feed passage or retention, secretion of saliva or buffers such as urea and bicarbonate for balancing ruminal pH, absorption of fermentation products like SCFA and NH_3 and passage of undigested dietary and microbial residues into the small intestine for further digestion (Merchen and Bourquin, 1994; González et al., 2012). However, ruminal microbial digestion can be inefficient despite the homeostatic mechanisms by the host, as considerable losses of feed energy occurs as heat or methane (CH_4) (Oenema, 2006). High quality dietary protein is degraded and utilized for synthesis of microbial protein. Microbial protein degradation also releases NH_3, which is recycled but partly lost in excreta as urea without being utilized (Merchen and Bourquin, 1994).

Carbohydrates and proteins are the major nutrients supporting rumen microbial growth (Hoover and Stokes, 1991). Forages differ in concentration of carbohydrates and protein and therefore will exhibit variability in the rate and extent of carbohydrate fermentation and protein degradation in the rumen (Gozho and Mutsvangwa, 2008; Foster et al., 2011). Barley and corn grains are common feed ingredients for cattle in western Canada. Barley grain has lesser proportions of starch (57 to 58%) compared to corn (72%) (Gozho and Mutsvangwa, 2008). Moreover, the greater starch fermentation rates in the rumen and reduced starch turnover in the small intestine, further reduces the efficiency of barley starch digestion. However, this inefficiency of barley digestion relative to corn is compensated somewhat by virtue of barley's higher protein concentration (Khorasani et al., 2001). Protein degradation in the rumen results in more availability of N substrates for bacterial growth and hence it takes advantage of the rapid rumen fermentation by increased microbial protein synthesis (Khorasani et al., 2001).

To date, there have not been any studies evaluating and comparing the rumen metabolic characteristics of whole plant corn and whole plant barley forages, used in extensive winter grazing systems in western Canada. The objectives of this study were to evaluate the effect of three forages managed in the winter feeding systems; whole plant standing corn, swathed barley and barley hay on ruminal pH, digestibility, apparent DMI and rumen fermentation such as SCFA and NH_3 concentration.

4.2 Materials and methods

4.2.1 Animals, forage types and experimental design

Nine ruminally cannulated heifers were randomly allocated to 1 of 3 winter grazing systems either 1) grazing whole plant standing corn in field paddocks (SC); 2) grazing whole plant swathed barley in field paddocks (SB); or 3) round bale barley hay fed in drylot pens (BH) to assess effect of forage type on ruminal pH and fermentation characters. During the study, 3 cannulated heifers per system were housed within a paddock or pen along with intact animals as described in Section 3.0. All cannulated heifers were cycled through each winter grazing system on a 21 d interval. A replicated 3 × 3 Latin square design (3 squares), was used to determine the effect of forage type (whole plant corn, swathed whole plant barley and barley hay) on rumen fermentation characteristics.

4.2.2 Data collection

An adaptation period of 14 d was followed by 7 d of Cr_2O_3 dosing for the estimation of fecal output and feed digestibility, starting at d 15 to d 18 of the 21 d period. Finally, starting from d 19 to d 21, rumen fluid and fecal samples were also collected for 3 d for the estimation of ruminal concentration of SCFA and ammonia.

4.2.2.1 Rumen fluid collection

Rumen fluid samples were collected from the ventral sac of the rumen at 1000 h, 1300 h and 1600 h on d 19, 20 and 21 for determination of SCFA and ruminal NH_3 concentration. Rumen fluid samples were strained through 2 layers of cheese cloth and two, 5 mL and one, 8 mL aliquot were transferred to a 12 mL test tube. An additional tube with 8 mL sample was kept as reserve. Out of the two, 5 mL samples, one sample received 1 mL of 25% (wt./vol) metaphosphoric acid (H_3PO_4) and was used for analysis of SCFA by gas chromatography. The second sample received 1 mL of 1% sulphuric acid (H_2SO_4) and was used for estimation of ammonia-nitrogen (NH_3-N). All the samples were sealed and stored at -20°C until analysis.

4.2.2.2 Forage sample collection and rumen incubation

Forage samples were collected from each field paddock (SC and SB) and drylot pen (BH), before the 1000 h sampling on d 19, 20 and 21 corresponding to d 1, 2 and 3 of forage allocation. For the SC system, 3 random samples of whole plant corn were taken from the field paddock. Corn plants were clipped at an approximate height of 10 cm from the ground. Barley forage were collected from SB system by randomly collecting 3 samples of whole plant swathed barley from the field paddock. Similarly, 3 grab samples were collected from barley hay bales on the day of bale allocation in the drylot pen. All forage samples were composited, dried at 55 °C for 72 h in a forced air oven and subsequently ground to pass through a 1-mm screen using a Thomas-Wiley Laboratory Mill (Model 4, Thomas Scientific, Swedesboro, NJ, USA).

4.2.2.3 Faecal sample collection

During each 21 d cycle, all cannulated heifers were given a 14 d adaptation period, then starting on d 15, 5 g of chromium sesquioxide (Cr_2O_3) (Powder/Certified, Fischer Scientific) previously weighed in a filter paper was manually placed into the rumen through the cannula opening at 1000 h, 1300 h and 1600 h for a 7 d period. Steady concentrations of Cr_2O_3 were expected to be achieved over a 4 d period from d 15 to d 19 followed by fecal grab samples collected rectally over 3 d from each heifer after Cr_2O_3 dosing at 1000 h, 1300 h and 1600 h from d 19 to d 21 of the period. Faecal samples from each cannulated heifer were then composited on an equal weight basis by period each year and dried in a forced air oven at 55°C for 72 h, then ground to pass through a 1-mm screen using a Thomas-Wiley Laboratory Mill (Model 4, Thomas Scientific, Swedesboro, NJ, USA). All ground faecal samples were then stored at room temperature in snap cap vials, to be used for the determination of chromium concentration and indigestible neutral detergent fibre (iNDF) markers.

4.2.2.4 Indwelling continuous ruminal pH measurement

Starting at 0800h on d 15, rumen pH was measured over 7 d in each 21 d period. Ruminal pH was recorded in millivolt (mV) at 2-min intervals, using an indwelling ruminal pH measurement system known as the Lethbridge Research Centre (LRC) pH measurement system (Dascor Inc., Escondido, CA) as described by Penner et al. (2006). The pH probes were standardised at the beginning and end of each measurements in each period using a standard buffer solution at pH 4 and 7 at 39°C. The drift between initial and final standardisation was considered to be linear and the millivolt data obtained was converted to pH values. The ruminal pH of 5.8 was considered as the threshold for mild ruminal acidosis (Nocek, 1997; Penner et al., 2007). The daily minimum, mean, maximum pH, duration (h/d) and total area (pH × min) under pH ≤ 5.8 was calculated for each cow, by period across each year as described by Penner et al. (2007).

4.2.3 Laboratory analysis

Prior to each day of analysis, the test tubes containing rumen fluid samples for SCFA and ammonia-N estimation were thawed in a refrigerator overnight at 4° Celsius. All thawed samples were mixed thoroughly and composited by volume, for each d of sample collection in each period for each year.

4.2.3.1 Estimation of short chain fatty acids (SCFA)

Composited rumen fluid samples for SCFA estimation were mixed in a vortex and centrifuged at 12,000 × g for 10 min at 4° C using a Beckman Centrifuge (Model Avanti J-E; Palo Alto, CA), followed by a second centrifugation in a microcentrifuge (Beckman Coulter TM, Brea, CA) at 10,000 rpm for 10 min at 4° Celsius. The supernatant obtained after centrifugation was used for SCFA determination by a method modified from the procedure followed by Khorasani et al. (1996). Duplicate samples were prepared in GC vials (Agilent Technologies™, Santa Clara, CA) after mixing with isocaproic acid, which was used as an internal standard. A mixed standard that consisted of known amounts of acetic, propionic, butyric, isobutyric, valeric, isovaleric, caproic and isocaproic acids was used to set up the calibration curve. The prepared samples and standard were loaded onto the autosampler of Agilent 6890 series Gas chromatography system (Agilent Technologies™, Santa Clara, CA) with FID (Wilmington, DE and an Agilent 7683 Series Injector), for the determination of individual SCFA concentration in each sample.

4.2.3.2 Estimation of ruminal ammonia-N

The test tubes with rumen fluid samples were thoroughly mixed and then centrifuged at 12,000 × g for 10 min at 4° Celsius in a Beckman Centrifuge (Model Avanti J -E; Palo Alto, CA), followed by a second centrifugation in a microcentrifuge (Beckman Coulter ™, Brea, CA) at 12,000 rpm for 10 min at 4° Celsius. The resulting supernatant was prepared according to the phenol-hypochlorite method as described by (Broderick and Kang, 1980). All the prepared samples including blank and calibration standards (5, 10, 15, 20 and 25 mg/dL of NH_3) were read using a spectrophotometer at 630 nm to determine the NH_3 concentration.

4.2.3.3 Estimation of apparent dry matter intake (DMI)

Measurement of apparent DMI included estimated feed digestibility and fecal output using Equation 2.4 (Section 2.0). Feed digestibility was measured using iNDF as the internal marker and fecal output is estimated using Cr_2O_3 as the external marker as described by Dove and Mayes (2006).

4.2.3.3.1 Estimation of apparent dry matter digestibility

Apparent dry matter digestibility was estimated using iNDF as the internal marker following the procedure described by (Huhtanen et al., 1994). All ground feed and fecal samples were composited for each period on an equal weight basis. Samples were then weighed (3 g) and hot sealed into 5 × 10 cm nylon bags (model #BG510, Bar Diamond Inc., Parma, ID) with an average pore size of 53 ± 10 μm. All nylon bags were incubated for 10 d within 4 cannulated heifers housed at the University of Saskatchewan Beef Research Teaching unit. The heifers were fed on ad libitum barley silage during this period. After incubation, all bags were rinsed 5 times under a cold stream of tap water and dried at 55°C in a forced air oven for 48 h as described by Rosser et al. (2013). The dried bags were used for detection of NDF concentration following the procedure by (Van Soest et al., 1991). Feed digestibility was calculated using the ratio of the marker (iNDF) in the feed and feces as described previously (Equation 2.3; Section 2.0).

4.2.3.3.2 Estimation of fecal output

Ground feed and fecal samples were analysed for chromium concentration for determination of fecal output. Preweighed samples between 0.2 - 0.21 g were ashed in a muffle furnace at 450 °C overnight. This was followed by digesting the samples in phosphoric acid (Williams et al., 1962) following the procedure described by Souza et al. (2013). Finally, the concentration of chromium in the samples was detected using a flame atomic absorption spectrophotometer (Thermo ICE 3300 Series, Thermo Scientific, Cambridge, UK). Fecal DM output was then calculated using Equation 2.2 (Section 2.0).

4.2.4 Statistical analysis

Data were analyzed using Mixed Model procedure of SAS (Version 9.3, Cary, NC). The experiment design was a replicated 3 × 3 Latin square design to evaluate the effect of forage type on rumen pH, SCFA, NH_3-N, digestibility and DMI. The model included fixed effects of forage, year and square, with cow considered as a random effect. Mean separation was completed using the Tukey mean separation test and significance was declared when $P \leq 0.05$ and trends were reported when $P < 0.1$.

4.3 Results and Discussion

4.3.1 Rumen pH

Ruminal pH was monitored in the current study to examine the effect of forage type and d of forage allocation on pH. Previous studies on cattle grazing behaviour have reported that cattle were found to selectively consume the most palatable part of the forage such as grain and leaves when introduced to a new pasture (Heady, 1964; Launchbaugh and Dougherty, 2007). Based on this concept, it was hypothezised that the increased consumption of grain (Leonardi and Armentano, 2003) on the first or second d of forage allocation may predispose the cannulated heifers in the current study to lower levels of ruminal pH (Calsamiglia et al., 2002), which might have an impact on fibre digestibility (Stone, 2004) and subsequent forage intake (Plaizier et al., 2008). Qualitative observation on the first d of forage allocation confirmed that relative to the consumption of other plant parts, the cannulated heifers exhibited a preference for corn cobs in SC system and barley grain in SB system and no sorting behaviour was detected in the BH drylot system.

Subacute ruminal acidosis (SARA) is the digestive disorder that arises when the ruminal pH drops below the optimal pH levels for the effective functioning of the rumen microflora (Owens et al., 1998; Plaizier et al., 2008; Schwaiger et al., 2013). However, there is no consensus in the literature in determining a threshold to detect subacute ruminal acidosis. A pH threshold of 5.8 and 5.5 is suggested by several researchers to delineate SARA in dairy (Beauchemin et al., 2003; Penner et al., 2007) and beef cattle (Wierenga et al., 2010; Zhang et al., 2013), respectively. Cattle fed on high concentrate diets have greater rates of SCFA production (Gabel et al., 2002; Calsamiglia et al., 2012) and absorption (Dirksen et al., 1985; Gabel et al., 1991), which likely increases the risk for acidosis (Dohme et al., 2008; Penner et al., 2009). Hence, it is reasonable to have a higher pH threshold in dairy cattle, since these animals are being fed a ration higher in forage to concentrate ratio. Under these circumstances in the current study, it seems appropriate to consider a higher pH threshold of 5.8 instead of 5.5, to demarcate the incidence of ruminal acidosis in beef heifers used in the current study, as these animals were fed solely a 100% forage diet.

The data collected from the indwelling continuous pH evaluation system (Penner et al., 2006) corresponding to d 19, d 20 and d 21 in each period in each yr was analyzed for changes in ruminal pH. These 3 d (d19, 20 and 21) correspond to d 1, d 2 and d 3 of forage allocation, respectively. The effect of forage allocation on pH is presented in Table 4.1. A significant effect ($P < 0.001$) of d of forage allocation was evident for all pH variables measured (Table 4.1). As expected, a daily variation in ruminal pH parameters was evident in heifers consuming whole plant corn and swathed barley in the field grazing systems (SC and SB).

There was no effect ($P > 0.05$) of d of forage allocation on ruminal pH in the drylot treatment (BH). As barley forage matures from boot to dough stage, the starch content increases with grainfill (Aasen, 2007) and the leaf to stem ratio declines (Nelson and Moser, 1994). Being harvested at the boot stage (Table A.1), barley hay used in the drylot system was lower in grain to leaf and stalk ratio (Aasen, 2007), compared to swathed barley forage. Therefore, the heifers on barley hay failed to exhibit a preferential sorting for grains and this explains why there was absence of ruminal pH differences with the day of forage allocation.

The minimum pH increased ($P < 0.01$) from d 1 to d 3 for heifers grazing corn and swathed barley. The area and duration under the threshold pH of 5.8 also showed a tendency to decrease ($P \leq 0.1$) as day progressed from d 1 to d 3. However, there was no effect ($P > 0.05$) of the yr on the treatment interactions within the d of forage allocation and so it was removed from the model. Results from a recent study by Rosser (2014), evaluating the effect of frequency of forage allocation on DMI and rumen fermentation characteristics in heifers fed whole plant oat forage (hard dough and ripe stage) in confined pens are in agreement with observations in the current study as the minimum and mean ruminal pH increased ($P < 0.05$) from d 1 to d 3 of forage oat allocation (Rosser, 2014). DeVries et al. (2005) also observed increased consumption of grain from whole plant forage in the initial d of feed allocation can reduce the quality of forage that is available for consumption in the subsequent days.

In the current study, the interpretation of pH change results suggests a selective consumption of the energy rich (starch) plant parts such as cobs from the whole plant corn (SC) and barley grain from the swathed barley (SB), by animals in the first day of forage allocation. As a result heifers grazing whole plant standing corn or swathed whole plant barley were more vulnerable to an acidotic challenge on the day of introduction to a new forage allocation (d 1) and the risk likely decreased in the subsequent days (d 2 and d 3) of grazing.

Treatment and treatment × year interactions were observed for minimum pH, mean pH, maximum pH and area and duration under pH < 5.8 (Table 4.2). However, the treatment × year interaction was significant ($P < 0.05$) only for whole plant corn (SC) and swathed whole plant barley (SB) forages. Lower values for minimum and mean ruminal pH ($P < 0.001$) and increased ($P < 0.01$) duration and area the pH was below 5.8 were observed in heifers grazing whole plant corn (SC) in yr 2 and heifers grazing swathed whole plant barley (SB) in yr 1, when compared to heifers grazing whole plant corn in yr 1 and swathed whole plant barley in yr two, respectively.

Table 4.1 Effect of day of forage allocation and forage type on rumen pH variables

	Treatment											
	Whole plant corn			Swathed barley			Barley hay				*P*-value[2]	
Ruminal pH	d 1	d 2	d 3	d 1	d 2	d 3	d 1	d 2	d 3	SEM	Day	Day × Trt
Minimum	5.5d	5.7cd	6.5ab	5.5d	5.8bcd	6.3a	6.0abc	6.1ab	6.2a	0.09	<0.001	0.005
Mean	6.2	6.3	6.5	6.2	6.3	6.7	6.5	6.5	6.7	0.07	<0.001	0.259
Maximum	6.9	6.7	6.9	6.9	6.8	7.0	7.0	6.9	7.2	0.07	0.002	0.572
Duration < 5.8	321.7	194.0	31.6	421.1	212.0	57.5	113.2	45.0	2.7	47.6	<0.001	0.120
Area < 5.8	142.1	61.0	6.7	141.8	24.8	0.6	12.5	7.4	0.2	25.7	<0.001	0.059

[1]Data from 3 d of indwelling pH measurement
[2]Trt = treatment effects; Yr = year effects; Trt × Yr = treatment by year interaction
[a,b,c]Within a row, means with a different letter differ ($P < 0.05$)
SEM = standard error of the mean

Table 4.2 Effect of forage type and year on rumen pH variables, SCFA and ammonia concentration

Item	Treatment						SEM	*P*- value		
	Whole plant corn		Swathed barley		Barley hay					
	yr 1	yr 2	yr 1	yr 2	yr 1	yr 2		Trt	Yr[2]	Trt × Yr
Ruminal pH										
Minimum[1,2]	5.95ab	5.60c	5.71bc	6.04a	6.18a	6.04a	0.071	<0.001	0.274	<0.001
Mean	6.45ab	6.24bc	6.21c	6.59a	6.62a	6.57a	0.056	<0.001	0.403	<0.001
Maximum	6.83ab	6.80ab	6.73b	7.02a	6.96a	7.03a	0.059	0.009	0.026	0.020
Duration < 5.8	67.63b	297.2a	347.5a	112.8b	20.4b	86.8b	38.07	<0.001	0.539	<0.001
Area < 5.8	22.67bc	117.2a	86.47ab	23.50abc	1.11c	12.26bc	20.05	0.009	0.419	0.002
Ruminal SCFA, mM										
Total[3]	85.7abc	92.8a	92.7ab	76.6c	81.9abc	80.9bc	3.495	0.014	0.398	<0.001
Acetate	56.5ab	58.9a	61.8a	48.6b	55.7ab	52.3ab	2.343	0.124	0.083	<0.001
Propionate	14.1abcd	15.5ab	15.4ac	11.8d	12.6bde	12.9cde	0.801	0.003	0.481	<0.001
Butyrate	7.9b	10.4a	7.6b	8.0b	6.5b	7.9b	0.532	<0.001	0.024	0.047
Isobutyrate	0.61c	0.67bc	0.75ab	0.78a	0.68abc	0.71abc	0.027	<0.001	0.158	0.754
Isovalerate	1.04ab	1.39a	1.15ab	1.37ab	0.99b	1.10b	0.094	0.007	0.005	0.231
Valarate	0.61b	0.92a	1.02a	0.92a	0.66b	0.05a	0.053	<0.001	0.005	<0.001
Ammonia, mg dl^{-1}	3.0c	2.2c	9.6a	5.6b	8.4a	5.2b	0.469	<0.001	<0.001	<0.001

[1]3 d of indwelling pH measurement

[2]Min = Minimum pH; Mean = Mean pH; Max = Maximum pH, Duration < 5.8 = Duration in min/d under the threshold pH of 5.8; Area < 5.8 = Area (min × pH/d)

[3]Measurements from rumen fluid samples collected at d 1, d 2 and d 3 of forage allocation

[a,b,c]Within a row means with a different letter differ (*P* < 0.05)

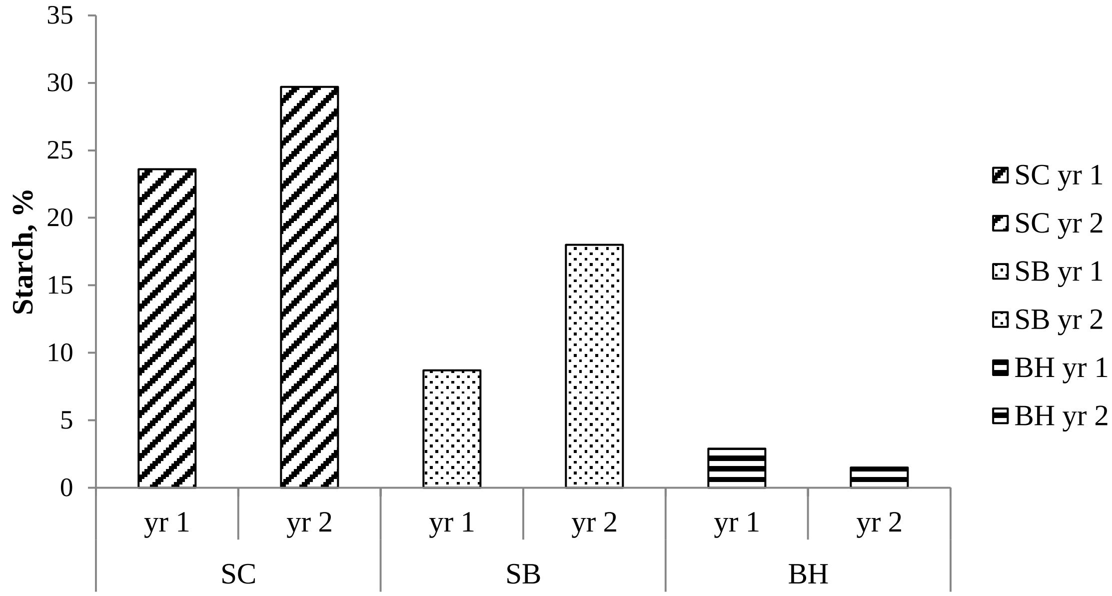

Figure 4.1 Starch levels of whole plant corn (SC), swathed whole plant barley (SB) and barley greenfeed (BH).

As discussed in Chapter 3, the forage offered to cows in SC, SB and BH systems in yr 2 was of greater maturity compared to forage in the first year of study. The analysis of starch composition of the 3 forages used in SC, SB and BH (Figure 4.1) indicates an increase in starch level in corn and swathed barley in the second year. The concentration of non-fibre carbohydrates (NFC) which is comprised of starch, simple sugars and soluble fibre was found to increase ($P < 0.001$) linearly in whole crop barley, millet and oat as they advanced in maturity in a study conducted by Rosser et al. (2013). The decreased ($P < 0.001$) minimum pH and increased ($P < 0.01$) duration of time and area under pH < 5.8 observed in cannulated heifers grazing whole plant corn in yr 2 may be due the increased plant maturity of the corn and higher starch concentration. Also observed was an unexpected predation of corn cobs by wildlife in yr 1 of the study which might have resulted in a significant loss of grain from the corn cob, thus decreasing the overall starch composition of the whole plant in yr 1 compared to yr two.

In contrast to what was expected, higher (*P* < 0.001) values for minimum and mean pH and lower values for maximum pH (*P* = 0.02) and the duration of time the pH was below 5.8 (*P* < 0.001) was observed in heifers grazing swathed whole plant barley (SB) in yr 2 of the study. Barley forage contained higher levels of starch in yr 2 compared to yr 1 (Figure 4.3), but it is questionable whether the starch contained in the barley grain was actually available to the cows. *In-vitro* studies by Baron et al. (1992) and *in-vivo* analysis by Rosser et al. (2013) found that starch digestibility in whole plant barley forage was not negatively affected by forage maturity. At the same time, starch composition of whole plant oat (Rosser et al., 2013) and barley (Baron et al., 1992) was found to increase with advanced stages of plant maturity. However, Rosser (2014) noticed a slight reduction in forage DMI (0.5 to 0.3 kg/d) and total tract starch digestibility of whole plant oat forage and a reduction in total tract DM digestibility (5 percentage units) but no change in starch digestibility for whole plant barley, when the forages were harvested at hard dough stage compared to late milk stage. This suggests the grain in whole plant forages may undergo some physiological changes with advanced maturity, resulting in either reduced animal consumption or availability.

Several possibilities may be related to the unexpected variability of pH parameters in heifers grazing swathed whole plant barley (SB) in the second year of the study. Firstly, increased fragility of forages due to maturity (Ulyatt, 1983) and higher precipitation rates between swathing and animal grazing (Aasen et al., 2004) could increase the effects of weathering (Baron et al., 2012), resulting in kernel losses in the barley plant (Stacey et al., 2006). Secondly, it is doubtful whether the starch contained in the barley kernel in more mature barley forage was effectively degraded in the rumen, since the outer pericarp in barley needs to be damaged to be made available for microbial digestion in cattle (Beauchemin et al., 1994; Rosser, 2014). It was observed by Morgan and Campling (1978) that 52.4% of whole plant barley was excreted in the feces without being digested when fed to dry dairy cows. Beauchemin et al. (1994) found that after mastication the whole barley kernels remained relatively intact when compared to corn kernels. Putting together these possibilities and the results obtained from the current study, it may be assumed that the excess starch present in the barley kernel (grain) was not effectively utilized by the cows and this in turn helped in preventing a decrease in ruminal pH in yr 2.

4.3.2 Rumen fermentation (SCFA and NH_3-N)

Significant treatment × year interactions ($P < 0.05$) were observed for total SCFA and acetate, propionate and butyrate concentrations (Table 4.2). Total SCFA, acetate and propionate concentration was similar ($P > 0.05$) for heifers consuming corn forage (SC) in yr 1 and swathed barley forage (SB) in yr 2 and also between heifers consuming corn forage (SC) in yr 2 and swathed barley forage (SB) in yr 1. Heifers consuming barley hay (BH system) did not show any significant variation ($P > 0.05$) in individual or total SCFA concentration between years. Butyrate concentration in heifers grazing corn forage (SC) increased ($P = 0.05$) in yr 2 compared to yr one. Heifers consuming swathed barley forage (SB) had lower ($P < 0.001$) total SCFA, acetate and propionate concentration in yr 2, however butyrate concentration did not vary ($P > 0.05$) between yr of study.

Production of SCFA in the rumen results mainly from the fermentation of structural and non-structural carbohydrates (sugars, starch and pectins), which constitute 70 to 80% of all cereal grains (Nocek and Tamminga, 1991; Allen, 1997) . The degradation of starch is highly variable across different diets (Nocek and Tamminga, 1991). Moreover, the concentration of starch in a feedstuff does not necessarily hold a relation to its degradability in the rumen (Nocek and Tamminga, 1991). The lower SCFA levels of swathed barley forage (SB) in yr 2 again supports the argument that even though starch concentration in whole plant barley was higher in yr 2 (Figure 4.3), it was not available for digestion and SCFA production in the rumen. Probable reasons may be increased loss of grains from the swathed forage resulting from increased fragility of more mature barley forage or reduced starch degradability in the rumen.

Increased concentration of SCFA is often associated with a drop in ruminal pH (Aschenbach et al., 2011). The evaluation of various experiments using ruminally cannulated dairy cows showed a negative correlation ($P < 0.001$; $r^2 = 0.13$) between ruminal SCFA concentration and mean ruminal pH (Allen, 1997). Similar to this, an increase ($P < 0.001$) in SCFA concentration and subsequent drop ($P < 0.001$) in ruminal pH was observed in heifers grazing swathed whole plant barley (SB) in yr1 compared to second year of study. However, for heifers consuming whole plant corn (SC) in yr 2, the decrease in ($P < 0.001$) minimum pH and increased duration under pH < 5.8 was not associated with an increase ($P > 0.05$) in total SCFA concentration.

The heifers grazing swathed whole plant barley (SB) and barley hay (BH) had higher levels ($P < 0.001$) of NH_3 in the rumen fluid compared to heifers grazing whole plant corn (SC). A significant ($P < 0.05$) reduction in NH_3 levels was observed for swathed barley (SB) and barley hay (BH) in yr 2 compared to yr 1. This may possibly be due to the high CP and low starch content of barley compared to corn and lower CP levels ($P < 0.01$) of swathed whole plant barley (SB) and barley hay in BH in second year of study (Table 3.2).

4.3.3 Forage digestibility and DMI

The observed treatment and year interactions in ruminal fermentation data (Table 4.2) may suggest for a decrease in starch degradability in the rumen with increased maturity of swathed barley forage (SB). Unfortunately, the digestibility calculations in the current study failed to produce valid results to discuss furthur. The major limitation with digestibility estimation was the difficulty in manually obtaining forage samples which best represented what the heifers consumed in field paddocks or pens. Future studies are recommended to use oesophageally fistulated animals to rule out experimenter bias while collecting forage samples.

4.3.4 Summary

The results of the current study suggest that grazing either whole plant standing corn and swathed whole plant barley can increase the risk of subacute ruminal acidosis in beef cattle which may have negative effects on animal performance over the long term. This also emphasizes the importance of good agronomic management practices such as careful planning of the seeding and harvesting dates of annual forages to ensure optimum levels of starch in the grain and also allocation of fresh forage to cows in a time limited fashion to prevent sorting for individual plant parts, especially grains. More studies need to be done to evaluate strategies that can be adopted to prevent sorting behaviour in cattle grazing whole plant annual forages. It is also suggested that future studies should incorporate oesophageally cannulated animals, which can be a practical alternative to rule out the individual bias when manually taking feed samples.

5.0 GENERAL DISCUSSION AND CONCLUSION

The ultimate goal of any cow-calf operation is to bring forth better cow performance and thereby maximise economic returns. Beef cow performance in winter is highly dependent on the prevailing environmental conditions, animal management and availability of good quality forage. Weather conditions are unpredictable, vary from year to year and have a predominant role in determining the success of extensive grazing programs. Adequate rainfall and warm temperatures during spring and summer is essential for adequate forage biomass production, which can support the cows later during winter grazing. Crop selection is also important because cool season and warm season crops respond differently with cool and warm environmental temperatures during growth. Apart from this, precipitation and daily temperatures also influence the date of seeding of forages and the date of swathing in a swath grazing system which inturn can result in a variation in forage maturity and quality with year. Winter conditions such as snowfall, wind and temperatures also show yearly variation, which makes certain years more favourable to beef cow grazing compared to others. However, despite of these uncertainities in weather, it has been found that efficient management practices such as ensuring availability of good quality forage at the time of grazing, allocation of feed in limited quantities to the cows, frequent evaluation of cow performance during the grazing period and monitoring for metabolic disorders resulting from feed sorting can rectify the impacts of weather to a certain extent. The objective of the current study was to make an economic comparison between whole plant corn grazing and swathed barley grazing to barley hay grazing in drylot pens over 2 consecutive years and to evaluate the treatment effect on beef cow performance and reproductive efficiency (Experiment 1) and to evaluate the effect of forages used in these winter feeding systems on rumen fermentation characteristics (Experiment 2).

Forages used in the winter grazing systems (SC and SB) in the current study differed in their yield and chemical composition between treatment and also between year of study. Results from experiment 1 suggested that forage corn produced more biomass per ha compared to barley forage used for swath grazing. Whole plant corn was higher in energy (TDN) but lower in CP, ADF, NDF, lignin and minerals when compared to swathed barley forage and barley hay fed in drylot pens. Yearly differences in forage nutrient composition is attributed to the differences in planting and harvesting dates which apparently resulted in an increased maturity of forages in year 2. However, the forages used in SC, SB and BH systems adequately met the NRC requirements of a dry pregnant beef cow in its second trimester of pregnancy in both years of study.

Cow performance parameters in the 3 winter grazing systems did not differ from each other except for increases in rib fat. An increase in rib fat was observed in SC cows compared to SB cows (1.6 vs 0.3 mm, respectively). Calves born to SC cows were also heavier at birth compared to SB and BH cows (43, 40, 40 kg, respectively). But SC had the lowest DMI compared to SB and BH cows (9.1, 14.3 and 13.0 kg/d, respectively). Interpretation of the results from experiment 1 suggests that the increase in energy density in corn or probably a higher forage digestibility (which estimation failed in the current study), has likely resulted in a better performance in SC cows in certain body performance and reproductive performance parameters compared to SB and BH cows. However, the cows in all the 3 winter feeding systems were able to maintain their body weight and BCS without any negative effects on cow performance or reproductive efficiency in both years of study (Tables 3.3, 3.4 and 3.5). Eventually, results from economic analysis revealed that total system costs in field grazing systems (SC, SB; \$2.06 and \$2.00/cow/d, respectively) was comparatively lower than the drylot system (BH; 2.75/cow/d), which highlights the potential of extensive grazing strategies in bringing economic advantages to the beef producer when compared to managing cattle in the traditional drylot systems.

The objective of Experiment 2 was to evaluate the effect of forages used in the winter feeding systems (SC, SB and BH) on rumen fermentation characteristics such as ruminal pH and concentration of SCFA and ammonia-N. Heifers were allocated fresh pasture (SC, SB) or new bale (BH) every 3-4 d, depending on the weather conditions. Incidences of subacute ruminal acidosis decreased as grazing progressed from d 1 to d 3, indicating a preferential selection for grains by the heifers. The results indicated significant treatment × year interactions from forages used in field grazing treatments (SC and SB) in all the parameters evaluated, while treatment × year interactions were absent in heifers fed barley hay in BH system. The treatment × year interactions in rumen fermentation characteristics in heifers consuming forage corn is explained by the increase in starch level in more mature corn forage in year 2 compared to year 1. Barley grain was also higher in maturity in year 2, but it is concluded that the increased fragility of grains may have resulted in a reduced consumption of barley grains by heifers and hence starch availability.

The interpretation of results in experiments 1 and 2, suggests that yearly differences in weather may have an impact on beef cattle performance in extensive winter management programs. However, the treatment × year interactions which were significant in the rumen fermentation characteristics in heifers used in experiment 2 did not show any possible relation to the cow performance or reproductive efficiency parameters in experiment 1. The difference in physiological status of animals used in the 2 experiments, small sample size and the short duration of study may be probable reasons for the failure to generate valid general conclusions from the results.

To summarize, since extensive grazing programs are highly influenced by weather conditions that exhibit variation from year to year, the underlying risk while adopting such management practices cannot be ignored. But looking at the advantages it offers in terms of economic returns and environment sustainability, it may be considered worth to take the risk of implementing overwintering management programs in western Canadian beef production systems.

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7.0 APPENDICES

APPENDIX A

Table A.1. Summary of seeding, swathing and harvesting dates

Item	Corn		Swathed barley		Barley hay	
	2012	2013	2012	2013	2012	2013
Seeding	Jun 7	May 24	Jun 8	Jun 6	Jun 10	Jun 6
Swathing/harvesting	.	.	Aug 18	Aug 26	Aug 10	Aug 20
CHU[1]	2085	2232	.	.	.	.
GDD[2]	.	.	921	941	818	859

[1]Data calculated from seeding until the first less than -3 degree celcius frost (SMA, 2010); CHU = [1.8 (Tmin – 4.4) + 3.3 (Tmax – 10) – 0.084 (Tmax – 10) ²] / 2, where Tmax = Maximum daily temperature, Tmin = Minimum daily temperature
[2]Data calculated from seeding until the swathing date; GDD = [(Tmax + Tmin)/2 – 5]

APPENDIX B

Table B.1 Chemical composition of forages in the winter feeding systems prior to winter grazing

Item[1]	% DM	CP, % DM	TDN, % DM	ME, Mcal/kg	Ca, % DM	P, % DM
September, 2012						
SC	24.5	7.8	66.2	2.4	0.23	0.20
SB	88.9	11.2	59.5	2.2	0.33	0.25
BH		12.7	60.1	2.2	0.41	0.27
September, 2013						
SC	26.2	8.6	72.8	2.6	0.21	0.21
SB	91.1	9.6	62.2	2.3	0.21	0.21
BH		10.4	66.6	2.4	0.28	0.23

[1]DM = dry matter, CP = crude protein, TDN = total digestible nutrients, DE = digestible energy, Ca = calcium, P = phosphorus. Analyzed by Strathroy Central Laboratory, Ontario

APPENDIX C

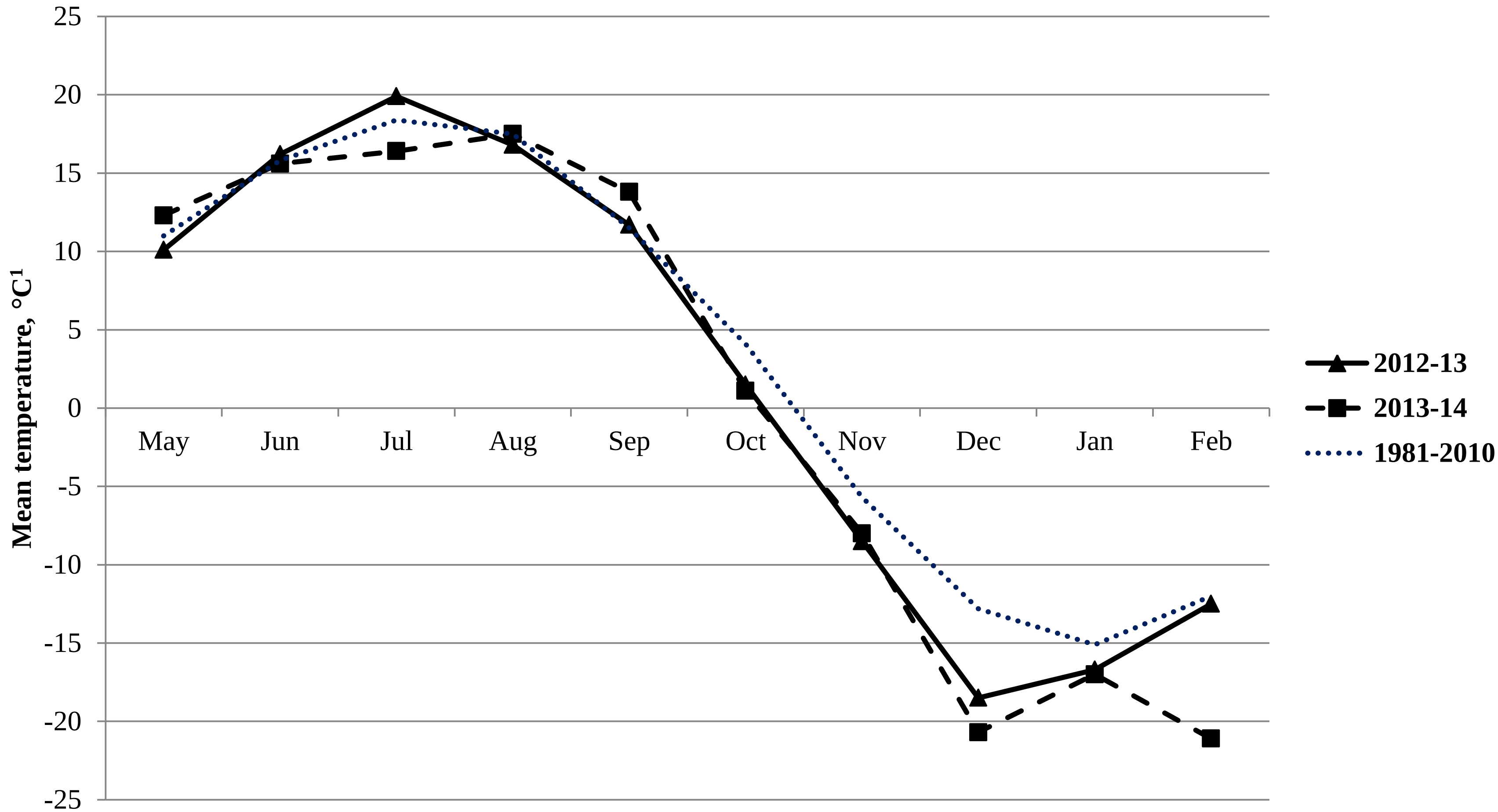

Figure C.1 Average monthly temperatures for year 1 (2012-13), year 2 (2013-14) and 30-yr average

[1]Temperature data from weather station, Termeunde Research Ranch, Lanigan. Long term (1981-2010) temperature average from Environment Canada's climate data online (www.climate.weatheroffice.ec.gc.ca)

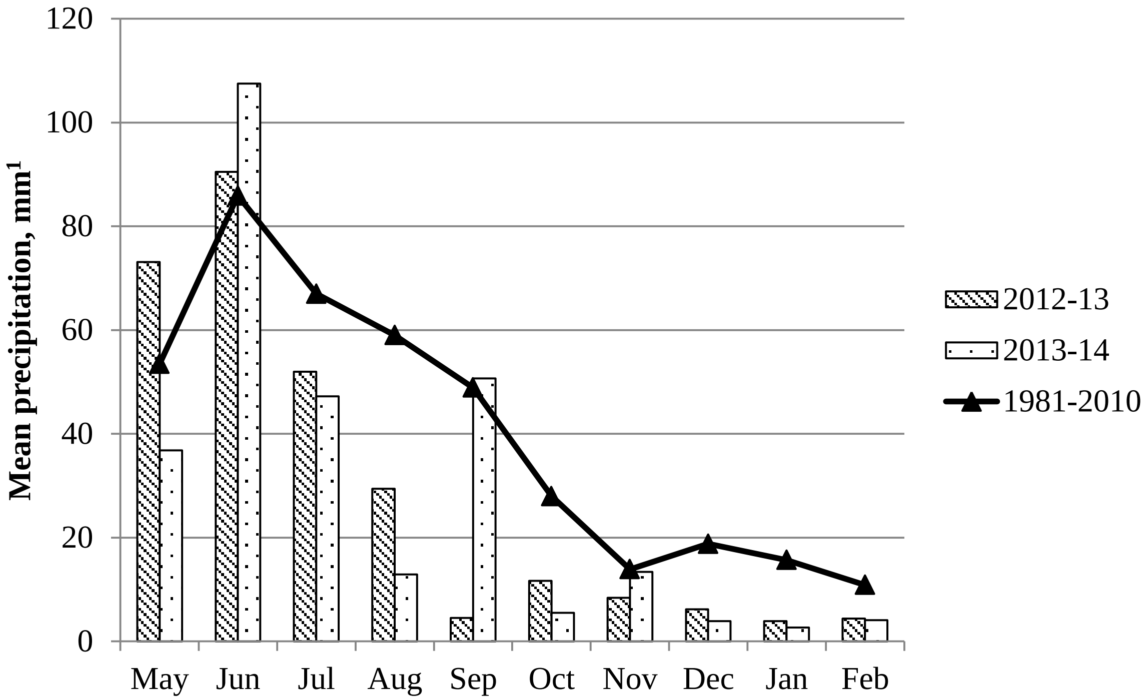

Figure C.2 Average monthly precipitation for year 1 (2012-13) and year 2 (2013-14)

[1]Meteorological data from Environment Canada's Climate data online (www.climate.weatheroffice.ec.gc.ca) for ESK, Saskatchewan

APPENDIX D

Table D.1 Effect of winter grazing system on soil nutrient levels (kg/ha)

Soil nutrient	Treatment[1]			SEM	*P*-value
	SC	SB	CON		
NO_3-N	74a	73a	23b	12.0	0.01
Potassium	116	91	82	14.2	0.24
Phosphorus	1200a	1150ab	1052b	38.8	0.05

[1]SC = site of whole plant standing corn grazing; SB = site of swathed barley hay grazing; CON = control site
[a-c]Within a row means with different letter differ ($P < 0.05$)
SEM = standard error of the mean